INDIA

THE PHYSICAL ASPECTS

K. SIDDHARTHA

CENTRE FOR THE DEVELOPMENT OF ENVIRONMENT AND RESOURCES

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TELEFAX — 011 5804269
E-MAIL—suhasini@bol net.in

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PREFACE

It is surprising and intriguing as to how even after 50 years of independence there is no book on Indian Geography that contains a detailed and authentic account of Indian Geography The only book that provides a detailed account of Indian geography was the one published in the 1960's — India A Regional Geography edited by Dr. R L Singh. Of course, it was a regional account and contains the most authentic reference on Indian geography. However, there is still no such systematic account on Indian Geography that can incorporate traditional as well as modern concepts

The present book along with its companion volumes is an effort in this direction Till Latur earthquake, the whole of Indian Peninsula was considered as a stable block, till now drought was considered to be only a metereeological phenomenon, flood, only a product of heavy rainfall and building of embankments the only remedy to controlling floods. However, this is not the case

The book INDIA THE PHYSICAL ASPECTS has been written with an environmental perspective in mind.

The basic characteristics of the book are it's down to earth language, designed layout for better comprehension, an environmental approach and a non technical representation for the benefit of non geographers. The book is a designed book where essential terms have been explained in bold and concepts which are not part of the topic but are nevertheless related to it have been explained in boxed sections.

The book is essentially written from an environmental viewpoint The analysis of the problems and their solutions carry that tinge and this is very much evident in chapters on Climate, Vegetation, Soils, Floods, Drought and Land Capability

The book could not have been in the present shape without the explicit and implicit help of of my well wishers, friends and students. My special thanks goes to Sanjay Ojha, Manoj Jha and M V Chandrashekhar who read the manuscript and pointed out certain deficiencies They have largely *made the book useful from the point of view of students.*

I also acknowledge the help I got from the Centre for Science and Environment, New Delhi and Centre for the Development of Environment and Resources (**CENDER**), Hyderabad, from whose publications many diagrams have been taken

I thank the Deputy Director, Mr K B Kapur, NBT, and the reviewers whose efforts have been largely responsible for the qualitative upgrading of the book

I acknowledge the enormous help I got from the writings of Mr. K S. Valdiya of Wadia Institute of Himalayan Geology and Anil Aggrawal of CSE Their writings and publications from where many diagrams have been taken

I hope that my friends, well wishers and students continue to provide enough motivation to me with their support and constructive criticism to make this and other books in the series even better.

K SIDDHARTHA

I

GEOLOGY

Introduction

The geological history of a country is an indispensable facet of its geography, because it shapes the features on the surface determines the structure on and within the surface with a wide range of rock types,which were not in the present shape since the birth of the planet Earth, rather they evolved gradually in space and time. The three geomorphic units of India, i.e., the Himalayas and its extension from the east to the west, the Indo-Gangetic plains to their south, and the Peninsular Plateau, all experienced different types of processes, tectonic activities in course of their evolution These varied processes and forces are reflected in their physiographical features The Indian Peninsula is a stable mass of Precambrian rocks which have remained in position throughout its geological history with few Phanerozoic (*see Appendix*-I) events of sedimentation during Gondwana period and Mesozoic era with the extrusion of the Deccan lava. The Himalayas and the mountain chain north of it are made up of Proterozoic and Phanerozoic sediments of marine deposits and are tectonically very much disturbed as a result of diastrophic movements of recent geological time. The Indo-Gangetic unit is of very recent origin formed in Quaternary era and is covered by sediments of recent age. There is yet a fourth division, though not so well marked is the coastal plains surrounding the Peninsula. Together with the continental margins, they are made up entirely of Recent or Holocene sediments.

Precambrian history of evolution

Precambrian history of the Earth covers the longest period of evolution of the Earth starting from the origin of the Earth to the formation of the super continent, Pangaea India, particularly the Peninsular area was a part of this super continent and so

experienced the forces affecting the Pangaea during that time. The earliest terrestrial crust was formed by the cooling of hot molten and gaseous substances between 4.2 and 4 5 b y. ago and the earliest continental crust was between 3.8 and 4.0 b.y. ago. Some parts of the continental areas experienced tectonic stability and were not affected by mountain building activities These are known as **cratons** and are composed of oldest rocks The craton, though on the whole a stable unit, were also affected by mild vertical movements in different parts. The absolutely stable and rigid parts are represented by Precambrian crystalline rocks of the basement and are known as **shield** and the portion with mild vertical movements which were affected by subsidence and were covered with sediments are known as **platforms.** Indian Peninsula, a craton, also has shield which is surrounded by platforms which were covered by sediments in later period The craton consists of a Precambrian basement which evolved in four phases-sedimentation, magmatism, plutonism and orogeny.

The oldest rocks (3200-3000 m.y.) are ultrabasic, basic and schistose amphibolite which together *constitute the Sargur schist complex and are found* in Dharwarian terrain These represents **Older Green Stone Belt** Due to tapping of undifferentiated material of the upper mantle through deep fractures in the thin acidic crust, green stone belt thickened. The sagging of the crust along the fractures later provided sites for sedimentation and volcanism, followed by deformation giving rise to fold mountain belt and formed the basement for the deposition of the volcanic-sedimentary succession known as Dharwar supergroup representing **Newer Green Stone Belt.** Emplacement of granitic plutons in the various provinces of Peninsula, marks the stabilisation of various provinces like Dharwar, Eastern Ghat, Central India, Singhbhum-Orissa and Aravalli-Bundelkhand The culmination of the life of an orogen, is the evolution of craton, which is a composite of many former mobile belts. While one part of the crust was stablizing the other was experiencing mobility. Thus, the belts of mobility shift in space and time giving rise to **tectonic provinces.**

In the Peninsular region of India at least seven **tectonic provinces** are identifiable. The *Nilgiri province* of Charnokite, Khondalite and Granulites of 3200 m y ago and embracing also over 3800 m y. old Champua area in the Bihar-Orissa border and a part of the **"Banded Gneissic complex"** in Rajasthan is a product of the orogeny that climaxed about 2600+100 m.y ago. The **Dharwarian province** of **eugeoclinal lithological association,** moulded by Dharwarian orogeny of 2400-2300 m.y. ago accompanied by emplacement of the Closepet Granite. In northern India the Satpura orogeny (2000+100m y.) gave rise to the Aravalli - Bijawar province which encompasses the Sausar, Sakoli - Chiplighat of M.P and Gangpur-Dhanjori of Bihar and

Orissa. The Eastern Ghat orogeny (1600 + 100m.y.) gave rise to various **ultracratonic basin** for future sedimentation which is represented by the *Cuddapah, Pakhal, Kaladgi, Delhi, Semri* and *proto-Himalayas.* During the same time i.e., Precambrian (1600 m.y.) there was no sign of the present mighty Himalayas but the stage was being prepared by the nature through continued sedimentation on the basement in the Tethyan Himalayan zone which comprise of *Salkhala Group* in the northwestern Himalaya, the *Vaikrita Group* in the Spiti region of Himachal Pradesh and the *Bhimpedi Group* in the Central Nepal. The groups are overlain in a normal stratigraphic order by an unfossiliferous sequence of Late Precambrian to Early Palaeozoic. The *Jutogh Group* and *Daling Group* occurs as highest structural **nappes** in the Lesser Himalayan region which have been presumably derived from the basement successions of the Tethyan Himalaya. In this way the formations which developed in the Peninsular area during Precambrian/Archaen times can be summarised as below

Table 1.1 Precambrian and Archaean formations

Dharwar (S. India)	Central India	Eastern Ghat	Singhbhum	Aravalli Bundelkhand
Closepet Granite 2000-2380 m.y.	Dongargarh Granite (2200) Nandgaon Granite (2200) Sakoli Sausar Gr.		Mayurbhanj Granite (2000-2100), Gangpur Gr. Singhbhum Gr.Dhanjori Gr. (2100-2200)	Aravalli Gr.
Dharwar Super Group	Amgaon Gr. (2500)			Bundelkhand Gneiss
		Charnockite series (2600)		Banded Gneissic Complex
Peninsular Gneissic Complex (2600-2950)			Singhbhum Granite	
Sargur		Khondalite Series	Iron ore group	
			Older Metamorphic Group	

Source, Historical Geology and Stratigraphy of India

In late Palaeozoic a marine transgression took place by way of Salt Range and Rajasthan in the west, or through the Mahanadi graben in the east into these areas. This marine basin. **Deccan syneclise** extended over a vast area now covered under **Deccan trap** The syneclise achieved its maximum tectonic activation during Late Mesozoic and Early Tertiary when a thick succession of basalts were laid down along with **Inter-Trappean Beds**

Proterozoic history

Beginning of the Proterozoic eon is placed at about 2500m.y. ago and the era came to an end at about 570 m y ago. The Proterozoic Era began with a tectonic zonation of the Earth's surface into sedimentary basins of platform and geosynclinal type.

The intracratonic basins which were formed as result of the Eastern Ghat orogeny (1600-100 m y ago) experienced protracted period of sedimentation which gave rise to the *Cuddapah, Pakhal, Kaladgi, Delhi* and *Semri* group of rocks. These sedimentations were interrupted by an orogeny of milder type around 1100-1000m.y that brought into existence the Aravalli and also the arcuate synclinorium of the Cuddapah basin. This diastrophism was accompanied by granitic activity in the Aravalli (*Erinpura*) and along the faulted margins of basins in Bihar and Cuddapah. Almost at the end of Purana about 600 m.y. ago the *Vindhyans, Kurnool, Bhima, Indravati* and *Chattisgarh* groups were affected by the last of the Precambrian tectonic disturbances, which put an end to the Proterozoic era. During this period the Peninsula (a part of supercontinent) witnessed a phase of glaciation, the evidence of which in India is recorded in tillites found at the top of the Proterzoic-Bihar Group in Chattarpur district, Madhya Pradesh and **tillites** in Son valley in *Mirzapur-Sidhi* area.

There is a pronounced unconformity, the **Eparchaean unconformity**, representing major tectonic cycle, separating the strongly deformed and metamorphosed rocks of the Precambrian basement from this less deformed rocks of the sedimentary cover over the Indian Peninsula. Most parts of the Indian shield had stabilized at about 2100 m y. ago. They were partly submerged beneath the shelf seas giving rise to platform type of sediments preserved in the *Cuddapah Depression*, the *Kaladgi Basin* and the *Godavari Graben* and were deposited in a single sedimentary basin covering the thern central parts of the Indian Peninsula. The Middle Proterozoic Succession of orthern India is exposed in the **"Delhi Synclinorium"** of the Aravalli Range and presented by the geosynclinal sequence of the Delhi Supergroup. During the Upper

Purana time the shelf sea of the, southern central Peninsula had slightly shifted northward and, at the same time, it had enlarged north eastward to include the *Chattisgarh* and *Bastar* Depressions. In the northern part of the Peninsula the Delhi geosyncline had closed with formation of the Delhi orogen. The Bijawar shelf sea was replaced by the Vindhyan syncline over the northern edge of the Peninsula. The Vindhyan sea presumably extended northward into the Lesser Himalayan region. To the west of the Delhi orogen a series of volcanic rocks known as *"Malani Volcanics"* were laid during the time of deposition of the lower parts of the Upper Vindhyan The volcanics are overlain by arenaceous formations which resemble the uppermost succession of the *Vindhyan Supergroup* deposited in the *Vindhyan syncline* during the Late Proterozoic time.

The Precambrian-Cambrian boundary is represented by *Lolab formation* of Kashmir, *Kunzamala formation* of Spiti, *Martoli formation* of Nandadevi in extra Peninsula region and by part of *Bhander Group* of the Peninsula.

Table 1.2 Proterozoic formations of India

	Southern Peninsula	Northern Peninsula
Upper Purana	Kurnool Gr., Bhima Gr., Sullawai Gr., Indravati Gr., Chhattisgarh Gr.,	Upper Vindhyan Gr., Malani Volcanics
Lower Purana	Cuddapah Supergroup, Kaladgi Gr. Pakhal Gr.	Lower Vindhyan, Gwalior Gr., Bijawar Gr., Kolhan Gr., Delhi Supergroup.

Study only structure and relief

Source Historical Geology and Stratigraphy of India

Six

Geological evolution of the Peninsula To

(levels or stages)

There are four structural stratigraphic stages of the Precambrian Basement of Indian Peninsula. The Peninsular gneiss was emplaced after the formation of an Older Greenstone Belt which probably represents the relics of primordial crust. The gneisses themselves form the basement for the deposition of the first sedimentary volcanic sequence, now represented by a Newer Greenstone Belt. This gneiss formed the basement for all the succeeding rock formations. Thereafter, large intrusion of granitic plutons took place.

The Precambrian basement has seen many orogenic cycles. The oldest orogenic cycle is observed only as relics in some Archaen area. In Middle Archaen, the Singhbhum Keonjhar orogeny took place in northeast Peninsula (Iron Ore Series). The Late Archaen time witnessed extensive formation of Peninsular gneiss and Eastern Ghat trend. Towards the close of the Archaen era, Dharwar and Amgaon orogenies took place, which culminated with the formation of Bundelkhand gneiss in northern Peninsula.

Aravalli & Delhi orogeny are two diff^r orogenies.

During early Proterozoic, first Aravalli, and later Delhi orogeny took place and the Eastern Ghats were affected. During Middle Proterozoic, successive phases of orogenic events gave rise to Satpura and in Late Proterozoic, orogenic cycle took place in Shillong plateau and Travancore region. At the same time massive sedimentary deposition took place, covering a major portion of the Peninsula

Fig 1B.1: The tectonic framework of India

known as Cuddapah depression. In Middle and Upper Proterozoic, Vindhyan syneclise were formed having been deposited directly over Precambrian Peninsular Basement emerging out of the sedimentary cover in the northern part of the syneclise, comprising of gneisses and magmatite in the form of Bundelkhand Massif (Fig. 1B1.1).

During Middle and Upper Proterozoic, Chhattisgarh and Bastar depressions were formed.

The Lower Palaeozoic formation is conspicuously absent from the Indian Peninsula. Thick successions of Upper Palaeozoic and Mesozoic rocks were deposited in three great graben type basins Narmada-Sone-Damodar, Mahanadi and Godavari. The deposits of these grabens (fluviatile and lacustrine origin) are largely of terrestrial origin. While the grabens were formed in late Palaeozoic times sedimentation continued till the end of Mesozoic.

In Late Palaeozoic a marine transgression took place by way of Salt Range and *Rajasthan in the west, or through the Mahanadi graben in the east into these area.* This marine basin. **Deccan syneclise** extended over a vast area now covered under **Deccan trap**. The syneclise achieved its maximum tectonic activation during Late Mesozoic and Early Tertiary when a thick succession of basalts were laid down along with **Inter Trappean Beds**. During Mesozoic and Cenozoic a large portion of Northwest and Southeast of the Peninsula was under marine transgression leading to deposition of thick marine rocks on these continental shelves, e.g., Rajasthan shelf, Saurashtra Kachchh shelf, etc.

In Southeast coastal region, the three shelves were Thanjavur, Godavari and Cuttack shelves, in which Palaeogene and Neogene rocks were deposited. At about the same time, the oil producing (Palaeogene-Neogene) North Shillong shelf and upper Assam shelf were formed overlying the Shillong massif and the Mikir Hill Massif, respectively.

Palaeozoic history

The Palaeozoic Era began at about 570 m y. ago and came to an end at about 225 m.y.ago Palaeoclimatic and Palaeomagnetic studies have indicated that during the Palaeozoic era, India was joined with southern continents forming a supercontinent

known as ***Gondwanaland***. This supercontinent was encircled by a series of **geosynclines**. The polar wandering curve indicates that Gondwanaland was affected by much greater movements than ***Laurasia,*** which underwent a slow northward movement throughout the Palaeozoic. These two were close in the Devonian and separated again in the Late Palaeozoic to give rise to the Tethys sea. In the Himalayan region the sea had been there since the Late Precambrian. It is believed that the Late Palaeozoic events widened the preexistent *proto-Tethys* of the Himalayan region and connected it with the Tethys of the west. Except for a northward drift nothing happened to these continents until in the Late Triassic to Early Jurassic. Stratigraphic records indicate a typical character for the tectonic movement during the early Palaeozoic time. The Cambrian and the early parts of the Ordovician periods experienced a general subsidence which led to the deposition of thick sedimentary sequences. This trend was reversed during the later parts of the Ordovician Period and during the Silurian period leading to a world-wide **marine regression** and emergence of several mountain chains. There were two orogenies, **Caledonian** and **Hercynian** during the Palaeozoic

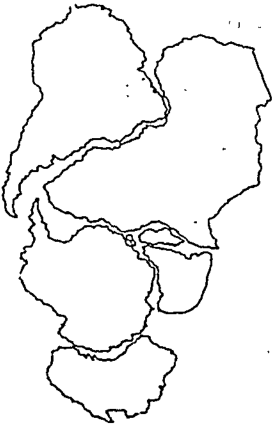


Fig 1 1. The position of India in Pangaea

In India, the **Palaeosea** (Vindhyan Sea) that covered the northern part of the Peninsular region during the Late Precambrian times gradually receded at the dawn of the Palaeozoic Era. A fairly continuous phase of sedimentation has been recorded in the Tethyan Himalayan Zone for almost entire Palaeozoic Era. The Tethyan marine basin of the … an and Hercynian orogenic ph … to the shallowing of the basin … ian tectonic phase is represented in the northwestern and eastern Himalayan belt by episodes of sub marine and coastal volcanism.

The Upper Carboniferous Epoch marks the beginning of a major cycle of continental sedimentation over the Indian Peninsula which began with glaciation phase, the traces of which are recorded in the form of/**tillite beds.** During the Lower Gondwana sedimentation, two phases of marine transgression took place in Peninsular India, the first as an extended arm of the Tethys through Sikkim to Central India and the second along the Narmada valley and represented by marine intercalations at *Manendragarh* and *Umaria*, respectively. The glacial deposits are overlain by a vast thickness of rock succession of continental facies represented by *Gondwāna Supergroup* of Permian-Early Cretaceous formation.

The marine Palaeozoic formations of India is represented by the *Dogra slates, Hazara slates* and *Attock slates* in the western Himalaya, *Shimla Group* in H.P., *Haimanta group* in Spiti (H.P.) and *Garbayang Formation* in northeastern Kumaon, *Gauran beds* in Lidar valley of Kashmir, *Muth Quartzites* in northern Kashmir, *Tanawals* in southwestern Kashmir, *Agglomeratic slates* in Pir Panjal range, Lidar valley, Chamba in H.P. and *Panjal Volcanics*. The sub-aerial volcanic activity persisted in Kashmir from Late Carboniferous to Late Triassic epoch. The marine condition in Middle to Late Permian time led to the deposition of fossiliferous limestone shales of *Zewan Formation*. In *Spiti valley* Cambrian succession is represented by the *Haimanta Group* of Cambrian age, *Muth quartzite* of Middle Devonian, and *Lipak formation* and *Po Formation* of Carboniferous age. In Kumaon Garhwal the Tethyan sequence is represented by *Garbayang Formation, Shaila Formation, Muth Quartzite, Kali Formation* and *Kringkroong Formation*. In Nepal Himalaya, the Palaeozoic Formations are represented by *Phulchauki Group, Nilgiri Carbonate Group, North Face Quartzite, Dark Band Formation, Tilicho Pass Formation, Tilicho Lake Formation* and *Thiri Chu Formation*. In the Lesser Himalayan region, during Lower Palaeozoic, formed the northern part of the Vindhyan sea sedimentation as represented by *Jaunsar Group* and

the Upper Palaeozoic rock formation are represented by *Balaini* and *Infra-Knol Formations*

Mesozoic History

The Mesozoic Era began at about 230 m y ago and closed at about 65 m y ago It has been divided into Triassic, Jurasic and Cretaceous period During this time, major charges took place in the distribution of continents and ocean. The Supercontinent of the Palaeozoic Era, Pangaea, was gradually torn apart during the Mesozoic Era Fragmentation of the Pangaea began with the opening of proto-Atlantic and proto- Indian Oceans. This breakup began with separation of North America and Gondwanaland in Late Triassic Epoch. Dismemberment of the Gondwanaland began in Late Jurassic Epoch which led to the separation of India and Africa from Australia, Antarctica and South America.

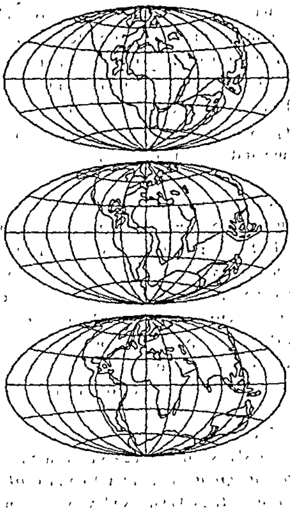


Fig.1.2. The rupturing of Pangaea

The Permian-Triassic boundary all over the world is beset with problems due to incomplete stratigraphic record because of the widespread regression at the close of Palaeozoic era. In many parts of India however, a fairly continuous succession of rock formations containing Permian and Triassic is found This boundary is represented by the *Guriyul ravine* of Vihi district of Kashmir, the *Triassic Succession* of Spiti, Kumaon and Zanskar which began with massive limestone and inter-calated shales containing three distinct ammonoid faunal assemblages viz. *Otoceras-Ophiceras, Meekoceras* and *Hedenstroemia-Flemingites* faunas. In the Gondwana sequences of India, the ...mo-Triassic boundary is evidenced at the base of Panchet formation.

During the Gondwana structural stage, intense block movements occurred along ancient faults, resulting in
basement lineaments. A n
period followed by a secc
an earlier phase in case of the Godavari Graben during this stage.

Further tectonic evolution of the Indian Platform during the Middle and upper Mesozoic developed along the shield area. Mesozoic sequence developed in all the peripheral structure, including parts of the Narmada- Son-Damodar Graben, Saurashtra -Kachchh and Rajasthan shelves, along the flanks of the Cambay and Indo- Sri Lanka Graben and the southern slopes of the Shillong Massif.

The Deccan Basalts

The Deccan basalts cover an area of 5,18,000 sq.kms. The lower traps occupying the eastern and southern portion of the basalt outcrop are characterised by tranquil eruptions of chemically uniform quartz normative thoeliite in horizontal manner. The upper traps which are confined to the west coast of India, Gujarat, Kachchh and Narmada valley show explosive activity. The lower traps characterised by quartz normative thoeliite show a total increase of alkalis from east to west suggesting that younger flows gradually were enriched in alkalis. The upper traps composed of thoeliite basalts also show unsaturated basalts (alkali-olivine, nephlenites, etc.) carbonatites, pyroclastic materials and Plutonic rocks. In recent years the G.S.I has classified a substantial portion of the Deccan traps into areas dominated by simple flows or compound flows. Both flows and ash beds generally indicate relative proximity to sites of eruption. Deccan basalts were

therefore, the consideration of events associated with the breakup is highly relevant. This was made possible either by

(1) Intracontinental rifting, interplate thinning and Mid Oceanic Ridge formation during the breakup of Gondwana land, ejecting enormous amount of lava General decrease in flow thickness and differentiation eastward favours that basalts formed in this way.

(2) Due to the passage of Peninsula over 'Reunion' island hot spot.

The nephlenitic magmas associated with Deccan traps may have been derived through low degrees of partial melting in the presence of small amount of water at 80-100 kms. depth. Quartz thoeliitic composition were derived from high degree of partial of peridotite at moderate pressure which corresponds to the pressure at the base of the crust. Alkali, olivine, basalts and nephlenites of younger age originated from garnet peridotite at high pressure along tectonically active belts in west India. Eruptions in Western India 2000 m thick dip near Mumbai Upper traps thin out towards eastern and southern areas.

The Deccan Trap and equivalent lava flows represent a significant event in the evolution of the Indian Platform. These diffusives cover an extensive area of the platform, mostly in central and western India, attaining in some cases vast thickness and thus obliterating the earlier tectonic history of the *Cambay graben* and the *Deccan syneclise* The evolution of the Deccan Syneclise was complete with the outpouring of the lavas, but the *Rajmahal* and *Sylhet* events continued into the Cretaceous. The main volcanic event occurred in a short period between 60-65 m y. ago and the second significant activity took 42-50 m.y. ago in the north eastern part. The Volcanic activities are related to the activation of the West Coast Fault and the faults of the Tapi and Narmada Grabens The lower and upper lava flows contain numerous **inter-trappean beds** of lacustrine and fluviatile origin

The **marine facies of** the Mesozoic Era developed in the Tethyan Himalayas, the Krol Belt of the Lesser Himalaya and the northwestern and southern parts of the Indian Peninsula and the rocks of continental facies constitute the Middle and Upper Gondwana sequences. In the *Tethyan Himalaya*, a fairly continuous succession of rocks yielding Triassic, Jurassic and Cretaceous period had developed in different parts. The Triassic and Jurassic rocks are predominantly of **carbonate facies** but the Cretaceous rocks show **flyscholdal** characters. The Tethys palaeo-sea became shallower during the Cretaceous period leading to gradual withdrawal of water towards the Indian Ocean which widened during the Mesozoic Era as a consequence of the northward drift of the Ind[illegible] ies in association with the deep marine [illegible] in the appearance of one of the most st[illegible] is the **Indus Ophiolite Belt** of Laddakh. The formations of the Mesozoic Era of Tethyan Himalaya are represented by a thick succession of limestone and shales in Kashmir-Chamba region, *Kalhel Limestone* in Kishtwar and Chamba region, *Lilang Group* and *Glumal sandstone*-and *Chikkim* limestone and shale in the *Spiti Valley*, *Namikla Flysch* in Laddakh, *Thini-chu* formation Nepal. In the Lesser Himalaya, the Mesozoic Era laid to the development of carbonate

predominant Krol formation overlain by a flyschoidal *Tal Formation* In between the deposition of these two formations, the phosphorite horizon represents the evaporite facies which is indicative of partial withdrawal of marine condition. In the Peninsula area **marine facies** (of the Palaeozoic Era are reported at Manendragarh and Umaria) have been extensively recorded in **Kachchh-Saurashtra** which started with **neritic facies of transgressive sea**, followed by deep water facies, shallow marine facies and lastly of mixed marine and continental origin; in western Rajasthan exposed in Jaisalmer region and grouped into *Lathi, Jaisalmer, Baisakhi, Badesar* and *Parihar Formations*, in Narmada Valley as *'Bagh' Beds, Lameta Beds*, in Cauvery Basin as *Dalmiapuram, Uttatur, Trichinopoly* and *Ariyalur* as a result of four successive phases of marine transgression and regression; in Meghalaya as *Mahadek formation.*

The term Gondwana sequence of India represents a 180 m.y. of sedimentation episode which had began in Permian period and closed during the Cretaceous period and is now exposed in three river valley grabens, viz., the Narmada-Sone-Damodar, the Mahanadi and the Godavari Grabens. The Gondwana sedimentation had started with deposits of glacial sediments of the Permian age The evidence of continental glaciation have been found as *Talchir pavement* in Chandrapur district of Maharashtra, the equivalent formations have also been recorded as *Tannaki Boulder Bed* in Kashmir-*Hazara, Mandbali Formation* in Garhwal, *Blaini Formation* in Himachal Pradesh.

The most prominent centre of glaciation was located in the southwest of the present Godavari Valley, north and northwest in the Damodar valley region. With the retreat of the glaciers at the close of glacial epoch, the irregular topography of the Indian Peninsula was filled in by swamps rich in vegetative matter which later became coaliferous as the condition became favourable for coalification. After the deposition of the coal bearing sediments, the basin was affected by a variable condition of deposition. The coal forming conditions were again ushered in during the deposition of the Upper Permian rocks, The Triassic Gondwana is characterised by cyclic alternation of arkosic sandstone and red shales whereas the Jurassic and Lower Cretaceous Gondwana formation consists of quartz-arenite, pebble sandstone and red siltstone association The Triassic sedimentation took place in streams of gentle slope whereas later sedimentation took place in streams of steeper slope.

The lower part of the Gondwana sequence were deposited in a cold climate, the coal bearing formations in humid sub-tropical and the Triassic formations in dry climatic conditions. The Lower Gondwana sequence is represented by the *Talchir*

Tillites, and the *Damuda Group*. The Lower Gondwana successions in the Peninsular India its development in different area has been given below:

Table 1.3. The Lower Gondwana formations

	Damodar Valley	Narmada valley	Mahanadi valley	Godavari valley
Upper Permian	Raniganj formation, Kulti Formation	Bijori formation, Motur formation	Kamthi formation	Kamthi formation, Motur formation
Middle Permian	(Barren Measure)			
Lower Permian	Barakar formation, Kaharbari formation	Barakar formation, Kaharbari formation	Barakar formation, Kaharbari formation, Umaria Marine Beds	Barakar formation,
Upper Carboniferous	Talchir formation	Talchir formation	Talchir formation, Mahendra garh Marine Beds	Talchir formation

Source Historical Geology and Stratigraphy of India

Rocks which can be correlated in Eastern Himalayans with the Peninsula are exposed in Darjeeling district as *Rangit Pebble slate formation*, in Arunachal Pradesh as *Abor Volcanics* and *Kirelong formation, Rilu formations* and *Bardi formations*

The Upper Gondwana sequence as developed in different parts of the Peninsula can be different parts of the Peninsula can be listed and correlated as below

DAMODAR VALLEY RAJMAHAL HILLS	SATPURA REGION	SONE-MAHANADI VALLEY	GODAVARI PRANHITA VALLEY
Traps			
Nipparia Beds	Jabalpur Beds		Gangpur formation
raps			

Lower plant beds	Chaogaon beds		Kota formation
Dibrapur formation	Unconformity	Parsora formation	Dharmaram formation
Supra-Panchet	Bagra conglomerate	Pali formation	Materi formation
Unconformity	Denva clay		Sempali formation
Panchet formation	Panchmarhi formation		Mangh Beds
		Kamthi formation	Kamthi formation

Source Historical Geology and Stratigraphy of India

Cenozoic evolutionary history

The Cenozoic Era comprises a history of evolutionary phase of the earth's surface of about 70 m.y and is the shortest and the most recent phase which started about 70 m.y. ago and ended at about 1.5 m.y ago. The physiographic features of India were shaped during the Cenozoic Era. The Era began with the outburst of lava flows over (1) the Indian Peninsula, a marine transgression over the northwestern Peninsula and (2) tectonic instability of the Himalayan basin. (3)

Evolution of the Himalayas

The protracted cycle of sedimentation which had started more than 1600 m.y ago in the Vindhyan basin was affected by an orogeny of Cambrian time due to which sea was divided into two basins - the Lesser Himalayan- Vindhyan in the south and the Tethyan in the north and the sedimentation in the Vindhyan basin came to an end The barrier later evolved into the Great Himalaya but the sedimentation continued in the Tethyan proper and in a narrow restricted part of the central sector of the Lesser Himalaya. The Hercynian orogeny which took place some 300 m.y. ago, forced the sea to vacate the Lesser Himalaya completely. Soon the sea water returned and created a continuous Tethys sea extending from Spain to Indonesia and the sedimentation continued in the Himalayan area until about 70-75 m.y. ago. The northerly drift of the Indian subcontinent collided in the Middle Eocene with Eurasian plate. Combined with the dominant northward movement of the Indian plate during the Mesozoic, the Indian sub-continent rotated clockwise, but remained between 50°S and 20°S. An island arc

consisting of oceanic volcanics and the adjacent trench sediments including turbidites, chert and pelagic clay that was existing in front of the Tibetan block, became welded to the Indian plate during the Late Cretaceous to Paleocene, representing the zone of collision and obduction of oceanic material as the **Indus-Tsangpo Suture zone** As a result of the collision of the continental blocks, crustal shortening to the extent of 300-700 kms took place, while the Indian plate slipped under the Tibetan landmass in the north causing the emplacement of ophiolite suite. All the subduction zones, viz. under the Afghan-Iran continental block and along the Patkai-Arakan-Andaman are emplaced with ophiolitic rock suit The initial collision involving the postulated island arc Laddakh, in the Late Paleocene-Early Eocene period was accompanied by clockwise rotation by 10°-20° of the suture zone in the north. The composite moved northwards more than 10° of latitude and then rotating clockwise by 10°-20° just after the final collision in Eocene-Oligocene times The two limbs of the Jhelum syntaxes show contrasting rotation the Pir-Panjal rotated clockwise by more than 20° Similarly, the Loralai range of Pakistan rotated clockwise by more than 50°

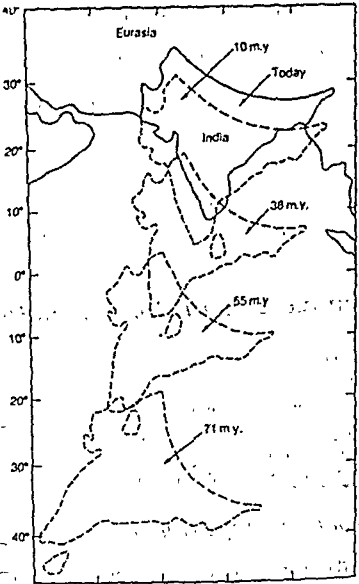


Fig 1.3. The northerly drift of Indian subcontinent and its subsequent collision with Tibet

2 times clockwise

During the ... of Indian
plate four phas
ords.

First, the **Karakoram phase** of the Upper Cretaceous to Paleocene during which included convergence of the Tibetan to the Indian plate and Indian plate, welding of the island arc-trench pair and emplacement of the ophiolite, as a result of which the Karakoram-Kailash-Lhasa belt emerged from the Tethys Sea and became an elevated landmass. During this period an elongate *Subathu* basin evolved to the south of the foot of emerging Himalaya in which Pre-Subathu and Subathu flysch was deposited.

The second phase, the **MallaJohar phase** of the Late Eocene to Oligocene was marked by the collision of the Indian plate and later emergence of the Tibetan plateau from the sea water; sheets of ophiolite and ophiolitic melange were thrust southward as nappes and a narrow elongated fore-arc basin developed in the suture zone in the Kargil-Hemis-Kailash-Shingatse zone.

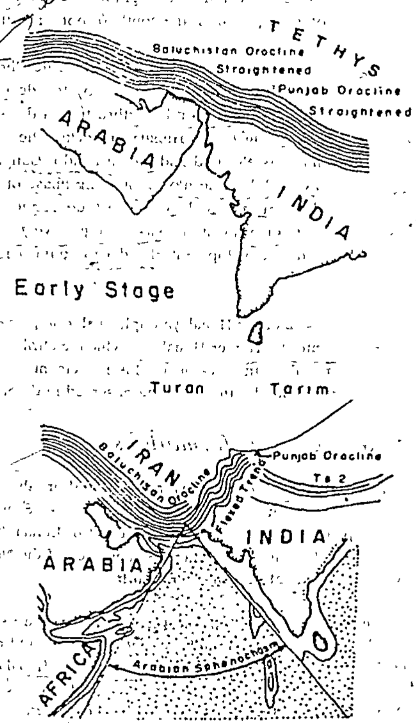


Fig. 1.4. The clockwise rotation of Indian plate after collision

The third phase known as the **Sirmurian Phase** of the

Middle Miocene was the strongest phase and was marked by folding, splitting, uprooting and southward displacement of the Lesser Himalayan nappes and the development of the **Main Central Thrust** bringing upto great heights the basement crystallines, emplacement of great volumes of granites in the Great Himalayan realm and development of a long basin in the southern border of the Lesser Himalaya.

The fourth phase ranging in age from the Late Pliocene to Middle Pleistocene, known as the **Siwalik phase** was marked by the development of **Main Boundary thrust** due to folding, faulting and overthrusting of the Siwalik sedimentary materials, pile over the advancing Lesser Himalayan rocks. The Karewas basin in the Tethyan realm in Kashmir was elevated and the vast Indo- Gangetic basin developed in front of the rising Siwalik hills. The next continuing Phase of Holocene brought the Lesser Himalayan and the Siwalik rocks over the Indo-Gangetic alluvial plain During these phases the basin of deposition was progressively shifting southwards which is depicted by gradual development of older to younger rocks from north, towards the south

The fifth phase of the Himalayan upheaval took place after the Pleistocene glaciers had receded into the Higher Himalayas which is attributed to the isostatic adjustment after the removal of the ice-sheet. This movement has not yet completely died as evidenced by slight adjustments being observed in different parts of the Himalaya.

Indian Cenozoic formations

Indian Cenozoic Formations are exposed in the Himalayan and the Arakan mountains and the shelf basins of Kutch- Saurashtra, western Rajshthan, Tiruchirapalli-Pondicherry and western coast of Kerala. The parallel belts, a northern belt of the Paleocene rocks and a southern belt of the Neogene rocks separated from each other by the **Main Boundary Fault.**

The Palaeogene rocks of the Lesser Himalayas are exposed in the Simla Hills as *Subathu formations* of marine facies and estuarine and freshwater facies. The neogene and freshwater facies, the Neogene rocks of the Himalaya representing the molasse facies are exposed in the Siwalik hills and other foothills comprising the Outer Himalaya and known as the *Siwalik Group* whereas those intermontane molasse facies, exposed in the Kashmir Valley at present are known as *Karewas formation*. The Indus iogeoclinal unit and the north of the Indus formation, overlain by molassic sediments

deposited in intra-deep and back deep molassic basins of Laddakh in the Assam-Arakan Region of Eastern India, its adjoining regions of Shillong-Mikir Plateau also exposed vast thickness of Tertiary and Quaternary rocks and are represented by *Mabadek formation, Langpar formation* of shallow water open sea environment of deposition, the rising group of Geoclinal deposition, the *Tipam group, the Duplitila group* and *the Dibing group*

The Cenozoic rocks of the Andaman Nicobar island belong to the Arakan folded belt of eastern India and Burma and represented by rocks of Upper Cretaceous Palaeogene group and younger archipelago group. In the northwestern Penisula, after a brief phase of marine regression towards the close of the Cretaceous period, the region was once again submerged by a shelf sea during the Cenozoic period. The rock formations deposited during this phase of sedimentation in Sindh is represented by Ranikot. *Laki, Kirthar, Nari, Gaj and Manchar formation*; in western Rajasthan by *Palana, Khuiala Bandah* and *Jogira formations,* and the *Saurashtra-Kutch by Madha, Berwati, Lakhpat, Khari* and *Karkawati formation.*

The Cenozoic rocks of the south India were deposited in the coastal area of Cauvery Basin, Malabar coast of Quilon Basin and Coromandal coast of Godavari Basin In the Pondicherry area of the Cauvery basin, the Cretaceous rocks are overlain by marine succession of Paleocene-Eocene age. Widespread glaciation took place during the Plio-Pleistocene period in four phases. First, during the *Tatrot formation* followed by the *Sorra glaciation, Potwar glaciation* and the last one in the Potwar area indicated by boulder beds in the relevant formations.

The Pleistocene and recent coastal deposits are reflected by raised beaches on the Eastern Ghat, gradually diminishing size of Chilka lake, mud bark formation on Travancore and Malabar coast; the aeolian deposits of loess found in Punjab, Kashmir, Sind and Baluchistan, the Thar desert dunes of south eastern Rajasthan, the Bhabar and Tarai deposits in the foot hills of the Himalayas and the cave deposits in the Kurnool desert, Andhra Pradesh. Coastal dunes, river alluvium and laterites are the manifestation of recent activities taking place on the surface. A large part of the continental blocks are still under the imperceptible slow and secular episodic crustal movements that have been taking place since the beginning of the Quaternary period some two million years ago and are manifest in recurrent seisimicity, movement of rock masses along faults and thrust planes, subsidence and rise of the ground, structural deformation and development of peculiar geomorphic features.

Table 1.4 Major Indian rock formations since Precambrian

Recent	Recent alluvium, Sand dunes, Soils
Pleistocene	Older alluvium, Karewas of Kashmir and Pleistocene river terraces, etc.
Mio-Pliocene	Siwalik, Irrawaddy and Manchar systems, Cuddalore, Warkilli and Rajahmundry sand stone
Oligo-Miocene	Murree and Pegu systems; Nari and Gaj series
Eocene	Ranikot-Laki-Kirthar-Chharat series
Lower Eocene, Upper Cretaceous	Deccan Traps and Inter-trappeans.
Cretaceous	Cretaceous of Trichnopoly, Assam and Narmada valley, Girumul and Chikkim series; Umia beds
Jurassic	Kioto Limestone and Spiti Shales; Kota Rajmahal and Jabalpur series
Triassic	Lilang system including Kioto Limestone, Mahadev and Panchet series
Permian	Kuling system; Damuda system
Carboniferous	Lipak and Po series, Talchir series
Devonian	Muth Quartzites
Silurian	Silurian of Burma and Himalayas
Ordovician	Ordovician of Burma and Himalayas
Cambrian	Hemanta system; Garbagyang series
Precambrian	Cuddapah and Vindhyan system; Dogra and Simla slates; Martoli series
Archaean	Dharwar and Aravalli systems; Salkhala and Daling series, various gneisses

THE HIMALAYAS

ORIGIN

The origin of the Himalayas is related to continent-continent collision. The continent-continent collision occurs when two continental plates collide. As the continents carried by plates move towards each other, the ocean basin is reduced in size and eventually closed. The Himalayas were formed when Gondawanaland moved towards Eurasia or the Indian plate moved towards Eurasian plate eventually enclosing the Tethys sea.

The major events in the generation of the Himalayan mountain belt by continent-continent collision are

1. Geoclinal sediments occur along the margins of Indian plate and Eurasian plate.

2. The wedge of the sediments along the margins of the continents are deformed above the subduction zone as the ocean basin decreases in size. Subduction begins as the oceanic crust is consumed.

3. Collision forced some of oceanic crust (ophiolite assemblage) to be caught between two plates and squeezed upwards and plastered against the plates. This marked the site of welding of two plates called has suture zone. The Indus Tsangpo Suture Zone is one such zone.

As the continental crusts collide one continent moves into the subduction zone, its buoyancy prevents it from descending into the mantle more than perhaps 40 kms. below its normal level. Here two things had happened:-

(a) the Indian plate was thrust under the overriding plate, creating a double layer of low density which rose buoyantly to produce a broad belt of deformed rocks with adjacent high plateau, e.g., Tibet.

(b) Even before continental (ophiolite assemblage) were caught, masses became welded together and fragments of oceanic crust between them squeezed upwards and plastered against the plates, thus marking the site

of welding of two plates, hence called suture zone. The Indus- Tsangpo Suture Zone is one such zone.

4. The oceanic slab descending into the mantle becomes detatched and sinks independently. When the slab has been consumed completely, the volcanic activity and the earthquake it generated are ceased.

5. As resisting forces build up and convergence stopped, the mountain becomes eroded and adjusts itself isostatically.

EVOLUTION

The upliftment of the Himalayas was accomplished in a series of five impulses punctuated by intervals.

The first upliftment took place in Late Cretaceous-Early Eocene time along the northern border of the mountains leading to a palaeo-island arc system that was formed at the commencement of Himalayan orogeny. The clue to this volcanic activity is found in a 500 kms. long sequence of volcanics beginning from Lato called the Dras Kohistan range. Here the reddish mountain slopes bear evidence of the extensive volcanism that once took place. At the same time intense deformation, regional metamorphism and emplacemnt of granitic gneisses took place. The Tethys sea was furrowed into longitudinal ridges and basins. These basins became the site of thick accumulation of flyschoidal sediments during the Palaeogene times.

The second upliftment which started in late Eocene times resulted in deformation of Tethyan Himalayan zone and emplacement of granite and granitic gneisses that comprise the higher Himalayan zone. The Lesser Himalayan Basin became shallower with the partial withdrawal of marine water. Brackish water sediments were laid in these.

The third upheaval which took place in Middle Miocene was most pronounced. Rocks of the Lesser H[illegible]

[illegible]

in which sediments were derived from freshly exposed Himalayan rocks.

The fourth upheaval took place in Pliocene-Pleistocene Epoch raising the Himalayan foothills. Broad folds were formed in the rocks of the foredeep. [illegible] the Lesser Himalaya from the outer [illegible] time.

The fifth and the final phase started when Pleistocene glaciers had receded into the higher Himalayas. As the ice sheet was removed there was isostatic upliftment. This upliftment due to isostatic adjustment is still in progress.

12225

STRUCTURE

श्री बुलबी नाराफ फेरेक्षा

On the basis of the geological character four longitudinal belts are broadly identified.

1. **The Siwalik belt** also known as **Sub-Himalaya** is the youngest part of the mountain chain. The rocks that constitute the chain consist mainly of alternating sequences of sandstone-siltstone-clay. Structurally Siwalik belt is characterised by broad open folds. However, towards its northern limit there is a greater deformation as reverse faults became common culminating factor in a major prominent fault which marks the northern boundary of the Siwalik group and is known as Main Boundary Thrust (MBT) and indicates the limit to the north of which no Siwalik sedimentation has occurred.

   third stage of uplift

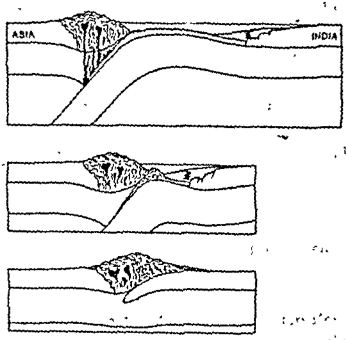
   The lower Siwalik consists mainly of red sandstone alternating with reddish [illegible] and the upper [illegible]

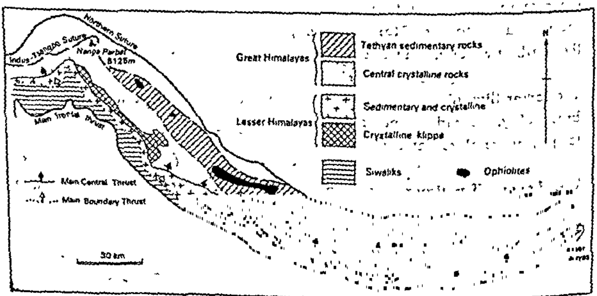
   last stage of uplift

2. **Lesser Himalaya** [illegible] re the Siwalik [illegible]

   The Lesser Himalayas are characterised by large thrust sheets (or nappes) which are caused by certain rock units moving over great distances and overriding the younger ones. These nappes are found in Garhwal, Simla and Kashmir. In Kashmir nappes have two groups, the outer thrust called Murree and the inner thrust called Panjal. The highest thrust sheets consisting of Precambrian crystalline rocks were derived from central crystalline zone during Tertiary deformation. The crystalline rocks rest tectonically over less metamorphosed Lesser Himalayan formations. The largely unfossiliferous

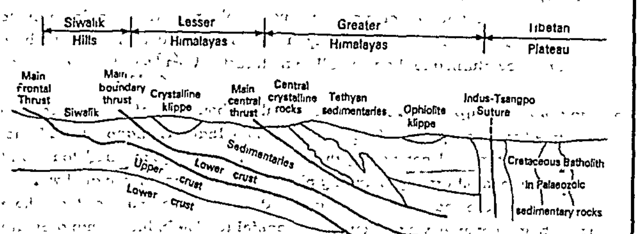
Stages in the evolution of the Himalayas





The Sructure of the Himalayas

The Structure of the Himalayas



Edge of plates got broken by c and then laid in

nature of Lesser Himalayan formation belonging to Precambrian time is overlain by sediments of Gondwanaland Supergroup age which again are overlain by marine Palaeogene rocks. A series of thrust faulting has brought about a general reversal in stratigraphic succession. Thus, the youngest Palaeogene succession is overlain tectonically by late Palaeozoic-Mesozoic succession of the Krol belt which in turn is overlain by Precambrian rocks.

3. **The Central Crystalline Rocks (Axis)** The Central Crystalline Axis (CCA) is the general name given to high grade metamorphic rocks which form one continuous series from Kashmir to Arunachal Pradesh occupying the central part of the Himalaya. Thus, they are said to form the Central Axis. They lie north of the Lesser Himalaya separated by Main Central Thurst (MCT). The CCA consists of Precambrian rock intermixed with granitic plutons. The component rocks of the Central Crystalline Axis have been subjected to severe compressional forces causing heavy buckling and distortion. There is a common sequence of deformation in widely separated areas such as Lahul, Kamaon, central Nepal and Darjeeling.

Crystalline rocks → Igneous rock

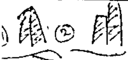
The region is considered to be the root zone of the nappe of Lesser Himalaya and perhaps acted as base for the deposition of the marine Tethyan succession.

4. **The Tethyan Himalaya** The Tethyan Himalaya is located north of the Central Crystalline Axis. It has four distinct areas that preserve geological record of about 600 m y., these are Kashmir, Lahul, Spiti, Kamaon and the Nepal

Sed rocks → Tethyans

Himalayan region which were once connected as a single unit. There is tremendous variation in rock type from huge boulder bearing conglomerate to fine grained black shales. The Tethyan zone is marked by intense folding, recumbent overturned fold and small scale thrusts. (folds are broken along their axis)

5. **The Indus Tsangpo Suture Zone.** The northern boundary of the Tethyan zone is marked by a conspicuous fault zone called the **Indus Tsangpo Suture Zone.** The sedimentary rock comprising this zone consists of flysch (sandstones and shales that exhibit rapidly changing physical characters). Associated with the flysch there are basic intrusive and extrusive rocks making the whole assemblage complex what is termed as **ophiolite**. The Indus Tsangpo Suture Zone (ITSZ) is highly deformed and is characterised by the presence of newly vertical thrust faults. (Mt. K2 and Rakaposhi)



Klippe → very intricate fold on a reverse or thrust fault.

Important Words

→ flake (made of basalt) ; ophiolite ; meta rocks

Cratons	Shield	Platforms
Older Greenstone Belt	Newer Greenstone Belt	Tectonic Provinces
Banded Gneissic Complex	Euogeoclinal Lithological Association	
Ultra cratonic basin	Nappes	Graben
Syneclise	Inter Trappean Beds	Tillites
Eparchaen unconformity	Geosynclines	Marine regression
Caledonian orogeny	Hercynian orogeny	Palaeosea
Facies	Flyschoidal	Neritic facies
Indus Tsangpo Suture Zone	Main Boundary Thrust	Main Boundary Fault
Ophiolites	Melange	

Mt. K2 & Rakaposhi ← ophiolite → sed, meta, igneous rocks and also called as melange

are ophiolites & are made up of basaltic ocean crust.

Mt. Rakaposhi → vertical sides (ice cream scoop).

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Sir

PHYSIOGRAPHY

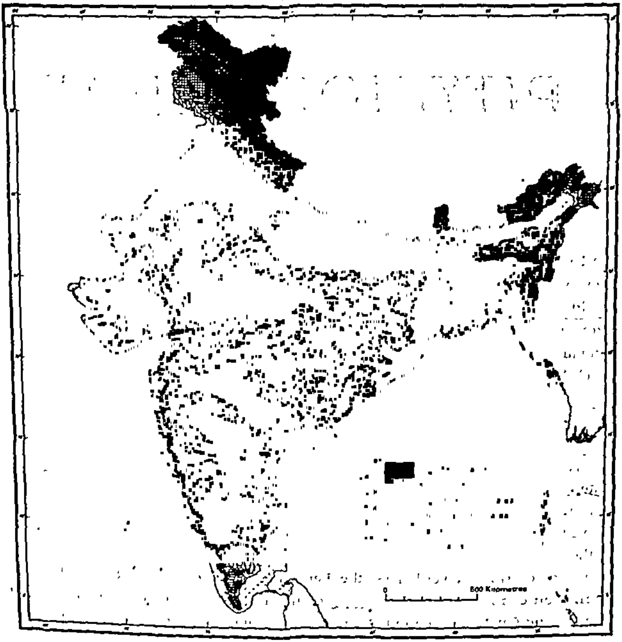
Introduction

India presents great diversity as re [illegible] graphy. The Himalayas are young fold moun [illegible] highly uneven surface, rugged topography and young river valleys; the Peninsular plateau is an old shield block having many relict features and old river valleys which have seen many cycles of erosion; the plains of northern India are aggradational features with a minimum amount of relief and very little gradient that are traversed only by some ridges which break the monotony of the plains; the coastal lowlands are flat with a rolling surface and many deltas (Fig.2.1)

The differences in the relief features is largely due to differences in the geological history and structure. The broad characteristics of the relief features of the Peninsular plateau emanates from its being a rigid mass of old rocks (a **craton**) which has remained almost free from any earth movements of horizontal nature. The fact that it has remained above the level of the sea since the Cambrian bears testimony to its stable nature. Most of the relief features are relict in nature and have withstood the onslaught of various agents of erosion. Nevertheless, the Peninsula has been and is being affected by **epeirogenic movements**. The uplift of the Deccan plateau continued during the Tertiary and Quaternary Period at a rate of 0.36 mm. per year. This vertical upliftment is the source of many surface features.

On the contrary, the Himalayas present a very youthful relief. The Himalayas, unlike *the relict mountains of the plateau are tectonic in origin and present many youthful* topographic features.

Fig. 2.1. The Physiography of India



The Great Plains are characterised by a low level relief. However, it is not monotonous but has diverse geomorphological features, such as **levees** and **bluffs** formed by the rivers along their banks. It portrays many features of maturity found in late stage of fluvial topography.

The Himalayas

The Himalayas (Sanskrit *'Him'-Snow, 'Alaya'-Home*) form the greatest mountain chain of the world. They form a highly rugged and continuous stretch of high mountainous country flanking northern India for a considerable length.

The Great Himalayas extend for about 2500 kms. between the Brahmaputra gorge in the east and the Indus in the west in an arc shaped manner. The Himalayas are 150-400 kms. broad and are convex to the south. Most of the Himalayan ranges fall in India, Nepal and Bhutan, but the northern slopes are partly situated in Tibet while the western extremity lies in Pakistan, Afghanistan and Central Asia. Himalayas are relatively broader in Himachal Pradesh and Kashmir and highest in Eastern Nepal.

The Himalayas consists of four main sections separated from one another by the gorges of the different rivers which traverse different ranges at different points from Arunachal Pradesh to Kashmir, e.g., the section between the Indus and the Sutlej covering 560 kms is referred to as the *Punjab Himalaya*, from the Sutlej to the Kali for a distance of 320 kms. as the *Kumaon Himalaya*; between the Kali and the Tista for 800 kms, it is called the *Nepal Himalaya* and from the Tista to the Dihang (*Tsangpo Brahmaputra*) for 720 kms. as the *Assam Himalaya*. Certain other regional names are also used to name the Himalaya, e.g., the *Punjab Himalaya*, the *Kashmir Himalaya* and the *Himachal Himalaya* and even the *Eastern Himalaya* and the *Western Himalaya*

The Kali river limits the Western Himalaya in the east, whereas a high transverse range, the Langalila, marks the western limit of the Eastern Himalaya. The Western

ir Himalaya, the South

iya from west to east.

The western part of ... *Darjeeling*

Himalaya and the ... remaining

portion of the Easte

In a similar manner, the Himalayan mountain chain all along its longitudinal axi is arranged into three main series of parallel ranges called the Greater Himalaya, th Lesser Himalaya and the Sub Himalaya or the Inner, Middle and the Outer Himalay (Fig 2 2) These ranges are separated by intervening spaces occupied either b longitudinal valleys of tectonic origin connected with the Himalayan uplift or plateau marking the erosion surfaces of an earlier age.

The Siwaliks

The Siwalik mountains represent the outermost range of the Himalayas. These mountains are over 2400 kms. long, overlooking the Great plains and running from Indus to Brahmaputra The height of the chain varies from 600 to 1500 m., but rarel exceeds 650 m. The Siwaliks are known by different names in different parts, e g., th *Jammu hills* in Jammu, the *Dafla, Miri, Abhor* and the *Mishmi* hills in Arunacha Pradesh, the *Dhang range*, the *Dundwa range* and the *Chiiria Ghati hills* in Nepal.

The Siwaliks are characterised by fault scarps, anticlinal crests and synclinal hills It is bordered invariably at the top by scarps and descends northward to flat floore structural valleys called ***duns*** The inner portion of the Siwalik comprises a series o parallel ridges and structural valleys rising to a maximum height of about 1500 m.

Many Himalayan rivers originating in the Greater Himalayas or beyond have forme steep gorge like valleys passing through the Siwalik.

The gorges of Tista and Raidak have joined to form a 90 kms. wide gap in th Siwalik range in West Bengal.

The Lesser Himalayas (Himachal)

The Lesser Himalaya in ancient literature has been referred as the *Himachal.* They lie to the north of the Siwalik range. Flat bottomed longitudinal valleys called *"duns"* in the central part, covered with gravel and alluvium, separate the Siwaliks from the Lesser Himalayas. The examples include *Dehradun, Kothridun* and *Patlidun.* The Lesser Himalayas form the most intricate and rugged mountainous system, 60-80 kms wide and 1000-4500 m high. The 60-80 kms wide mountains and valleys run in al

u. The mountains sometimes rise up to 5000 m. and the valleys touch 1000 m
re is general accordance of altitude among neighbouring summits giving the Lesser

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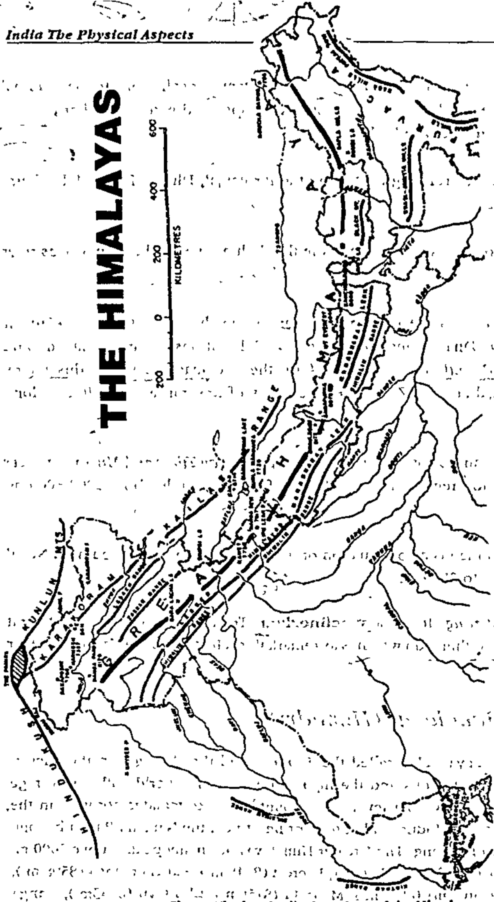

Fig.2.2.The longitudinal sections of the Himalayas

Himalayas the appearance of a highly dissected plateau. Locally, linear longitudinal ranges have also developed with steeper southern slopes and gentler northern slopes giving it a typical **hogback** type look.

The various westward running ranges are the Pir Panjal, Dhaula Dhar, Mahabharat and the Mussorie ranges.

The *Pir Panjal range* in Kashmir runs from the Jhelum river to the Upper Beas river for over 300 kms.

It extends eastwards as the Dhaula Dhar range, which rarely attains a height of more than 4000 m On Dhaula Dhar are situated the hill stations of Simla (2205 m.) and Pir Panjal The *Pir Panjal* and the *Banihal* are the two main passes in this range. Between the Pir Panjal and the Zaskar lies the valley of Kashmir about 150 kms. long and 80 kms wide.

The Dhaula Dhar ranges continue eastwards into the *Nag Tibba* and *Mussorie ranges* of the Garhwal Kumaon region. These hills are of lower altitude about 2000-3000 m. high

The Mahabharat range is a continuation of the Mussorie range into Southern Nepal with its summit rising to 3000 m.

The *Mahabharat range* forms a **synclinorium** ... abharat range is the v... Srinagar in Kashmir.

The Greater Himalayas (Himadri)

The Greater Himalayas, also called the *Himadri* and the *Bahirgiri* in the ancient literature, is a long, continuous and the highest range in the world with an average height of 6100 metres above sea level. The mountain arc terminates abruptly in the northwest overlooking the Indus, and in the northeast near the Namcha Barwa beyond which lies the gorge of Dihang. The Greater Himalayas has many peaks above 8000 m. such as Mt Everest (8848 m.), Kanchenjunga (8598 m.), Makalu (8481m.), Dhaulagiri (8172 m.), Mansalu (8156m.), Cho Oyu (8153m.), Nanga Parbat (8126m.) and Annapurna (8026m.) (Fig. 2.3.). The range is snowbound

throughout the year and a number of glaciers descend from it (upto 2440 m. in Kashmir and 3960 m. in the Central and Eastern Himalayas east of Himachal Pradesh).

Many of the Himalayan ranges in the Greater and the Lesser Himalaya are **orthoclinal** in their structural plans, i.e., they have a steep scarp like face on the southern side overlooking the plain while they incline gently towards the Tibetan side

The range is forbidding and it can be crossed by only few passes which are snow bound throughout the year. These passes are the *Burzil pass* and the *Zozi La* in Jammu and Kashmir; the *Bara Lacha la* and the *Shipki La* in Himachal; the *Thaga La*, the *Niti Pass* and the *Lipu Lekh* in Uttar Pradesh and the *Nathu La* and the *Jelep La* in Sikkim These passes generally lie at an altitude of 4570 m. and are used for crossing the Himalayas. They have in the past provided important means of communication between Tibet and India.

The *Zaskar range* lies to the west of the Greater Himalaya. The Nanga Parbat (8126 m.) forms its culmination in the northwest. The average height is beyond 6000 m. Although geographically it is confined to Kashmir-Himachal Pradesh-Garhwal region, it continues eastwards in the Dhaulagiri and further east. On the Zaskar are located the peaks of *Kamet* (7756 m.), *Nanda Devi* (7817 m.) and *Gurla Mandhata* (7728 m.). Beyond the Zaskar is the gorge of Indus.

The Trans Himalaya

The Trans Himalaya includes the Karakoram and the Laddakh ranges.

The Karakoram (called the *Krishnagiri* in ancient Sanskrit literature) lies to the north of the Indus. The Karakoram ranges extend from the Pamir, east of the Gilgit river crossing the regions of Gilgit, Balistan and Laddakh in Kashmir for about 600 kms. Its ... rkand river,

... The general

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... It. K2 (8611

m) (*Godwin Austen*, or *Qagir* as the Chinese have named it after occupation). Other important peaks rising abov... (8068 m.), Broad-Peak (8047 m.) and ... are the abode of some of the largest glaciers in the world-the Siachen, Baltoro, Biafo, Hisper

Gr Rona 8f

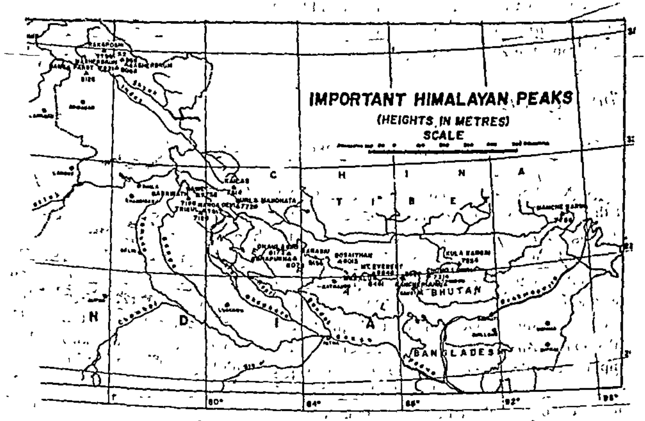
and the Rimu glacier of Pakistan. The Rimu is most notorious for breaching its walls and is one of the best examples of a **diffluent glacier**.

The Laddakh plateau is situated towards the north of the Karakoram range.

South of the Karakoram range, between the Indus and its tributary the Shyok, is the Laddakh range It extends for a length of 1000 kms. through the border of Tibet up to Mustang Its elevation, in general, is lower than that of Karakoram with only few peaks rising above 6000 m. The important peaks are Mt. Rakaposhi (7880m) and Gurla Mandhata (7728 m). Laddakh ranges can be crossed from many places- one pass, about 24 kms wide, has been created by Sutlej. The most important pass, however, is located to the north of Chomo Lahri through which flows the Niang, a tributary of the Tsangpo.

The Kailash range is an offshoot of the Laddakh range. Its average elevation is 5500-6000 m and the average width is 30 kms. The highest peak is Mt. Kailash (6714 m)

Fig.2.3. Important Himalayan Peaks



The Purvanchal (The northeastern Highlands)

After crossing the Dihang gorge in the east, the Himalayas bend towards south forming a series of hills with a north-south trend but slightly arcuate with the convex side facing west. However, the Purvanchal not only includes the lofty ranges which border India in the northeast but also the hills and plains in Manipur, Tripura and the adjoining districts of Assam. It may be further subdivided into six physiographic provinces Purvu-NEFA, Nagaland, the Manipur hills, the North Cachar hills, the Mizo hills and the Tripura hills.

Purvu NEFA has two major sections-the Mishmi hills and the Patkai Bum (range). The Mishmi hills contain the highest ranges of Purvanchal with many summits above 5000 m. There are several basins, e.g., the Taroan basin which is surrounded by several south flowing tributaries of Tulu river (Luhit). Dapha Bum (4758 m) is one of the highest peaks.

Many of the peaks of the Patkai Bum rise between 2000 and 3000 m. It is typically a *synclinal range built of strong Tipam sandstone. The axis of the syncline is roughly coincident with the crest of the range.*

The Naga ranges form the watershed between Nagaland and Burma. Saramati (3826 m.) is the highest peak on the Naga range and there are other peaks over 3000 m high. Towards west are the Kohima hills the highest peak of which is Japvo. The Kohima hills has a **range and valley type** of topography. Serrated ridges alternate with deep valleys containing fast flowing rivers.

This ridge and valley character becomes more pronounced in the Manipur hills which runs from the Tuensang hills in the north to about 24°N parallel in the south. The e[illegible] ipur hills run along the frontier between India and Burm[illegible] abut against the Cachar plains and hills. The Central part, 30 kms. broad and 50 kms. long, surrounded by mountains on all sides is a large basin. This basin is supposed to be the bed of an old lake whose remnant is still seen in the form of Loktak Lake having **centripetal drainage.**

A belt of hills and plains separate the Nagaland and the Manipur hills of the Purvanchal from the Meghalaya plateau. Along the eastern portion of Meghalaya runs the Barail ranges overlooking the Dhansiri valley in the north and the Silchar plains in

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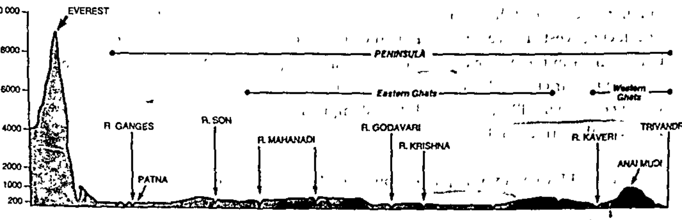

Fig.2.4. Cross section of the Himalayas from Everest to the Kerala coast

the south The Barail ranges present a **hogback** structure towards the western plains and merges imperceptibly with the Kohima hills in the east.

The larger portion of the hilly belt between Meghalaya and the northeastern ranges is known as the North Cachar hills. The average elevation is about 500 m. but here and there peaks rise to over 1000 m.

The southern part of the northeastern ranges are the Mizo hills (previously known as the *Lushai hills*) They are long north-south trending parallel ranges and intervening valleys Most of the ranges are of **cuesta** type and the slope is much steeper in the west than in the east

The Tripura hills comprise long ranges alternating with valleys. This range and valley type of topography has rendered communication very difficult, creating transport problem. Southwards, the array of hills pass into the Arakan Yoma of the Burmese coast.

One striking characteristic of the Himalayas is the difference in the arrangement of the mountain ranges between the Eastern and the Western Himalaya. The Eastern Himalaya rise rather abruptly from the plains of Bihar and Bengal with the highest peaks of Everest and Kanchenjunga located quite close together (Fig. 2.4). In contrast, the Western Himalaya attain height through a graded series of low hills (Fig. 2.5) The

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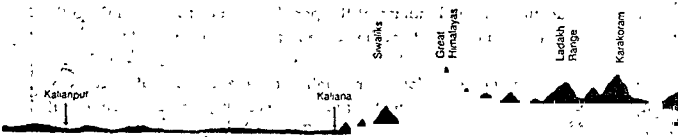


Fig.2.5. Section across Western Himalayas

first series is the Sub-Himalayan hills of Jammu and Kashmir, the second, the Lesser Himalayan ranges of Pir Panjal and the Dhaula Dhar and the third is the Great Himalayan range of North Kashmir and the Zaskar ranges. Northwards still, they are replaced by the Laddakh-Kailash and the Karakoram ranges.

The original relief of the Himalayas has been extensively modified by the Subaerial processes particularly by the work of running water and ice. This is evidenced by the deep gorges of the major rivers such as the Indus, Arun and the Brahmaputra The evidence of glacial erosion is scattered all over the Himalaya. These include

(i) Large block of rocks which have been transported from the high summits of the Himalayan ranges over long distances;

(ii) The Karewas of the Kashmir valley which have thick deposits of glacial clay and other materials embedded with moraines;

(iii) Many U-shaped and hanging valleys are found at elevations much lower than the position of the existing glaciers, and,

(iv) Moraine deposits found extensively along many river valleys, which form well developed terraces in many areas, particularly on the flanks of the surrounding mountain ranges, e.g. at Haridwar, Rishikesh, etc.

Significance of Himalayas

The Himalayas, *no doubt are one of the most important geomorphological feature* of India. More than that, however, is their contribution they have made towards shaping the destiny, life and culture of the people and most importantly to the economic prospect and prosperity of the entire region.

They deflect the BOC branch of S.W. monsoon westwards & stop

1. They are the *single most factor in controlling the climate of India*. The Himalayas are responsible for making the entire country tropical even though only half of India lies under tropics (see Climate). They are responsible for splitting the jet stream into two branches and these in turn have the most important influence on the monsoons. Besides, they block the intrusion of cold winds from Central Asia in winter.

2. The Himalayas are the birthplace of many Indian rivers. The snow fields **(himals)** and the glaciers are source of many rivers such as the Ganges, Yamuna, and many of their tributaries. Although the Himalayas do not form a perfect **water divide** they are also responsible for draining a large portion of water falling on them. Because it is a source of many rivers and also because of youthful topography, it is an important region for hydel power development.

3. The Himalayas are an important source of soil. The weathered debris are transported, reworked and then deposited by the river in plains when their velocity decreases. These rich alluvial deposits support the population of the Indo Gangetic plain.

4. The richness of the Himalayas in terms of its biotic resources is unparallel. Because of a variety of climatic conditions *even within the* Himalayas, there is greater diversity of flora and fauna. The Himalayas and the Khasi hills in northeast account for about 3000 of the 6700 endemic floras found. The Western Himalaya comprise silver fir, silver birch and junipers while the Eastern Himalaya and Assam has oaks, maples, alder, birch, bamboos and other tall grasses. The Lower Himalaya has many orchards of apple, pears, grapes, cherries, peaches, apricots, gooseberry, raspberry and strawberry. Some very beautiful flowers grow in the Higher Himalayas such as the **rhododendrons**.

The valley of flowers in Chamoli district of U.P is a very rich reservoir of endemic biodiversity.

5. The [illegible] valuable minerals, Copper, lead, zinc [illegible] tungsten occur in the Eastern and the [illegible]

6. The Himalayas are an important and still unexploited tourist destination. Many hillstations dot the Himalayas such as Pahalgam, Gulmarg, Srinagar, Amarnath, Dalhousie, Dharamshala, Shimla, Solan, Chail, Nainital, Almora, Mussorie, Ranikhet, etc. exchange for the country

Differnce between Peninsular Plateau and the Himalayan region

PHYSIOGRAPHIC DIFFERENCES

1. The Peninsular mountains are of relict type, a large portion of which have been subjected to extensive denudation while the Himalayan mountains are young folded mountains.

2. Peninsular region has flat, shallow valley with a low gradient This is because their channels have approached base level of erosion, while the rivers of the Himalayan region are in their youth.

STRUCTURAL DIFFERENCES

3. The Peninsular plateau is generally composed of crystalline rocks which have seen many cycles of granitic activity and metamorphism. They have remained little or unaffected since Palaeozoic by any earth movements, while the Himalayas are composed of sedimentary rocks which have been folded.

The Peninsular Plateau

That doesnt ha
been missed of R

The Peninsular plateau extends from the alluvial plains of Uttar Pradesh and Bihar towards the south to encompass the whole of the Peninsula. It has a general elevation of 600-900m. and makes an irregular triangle with its concave base lying between the Delhi ridge and the Rajmahal Hills and the apex formed by Kanyakumari. A part of the northern portion of the plateau is buried under the alluvium of Ganga and Yamuna. The slope of the plateau indicated by the Chambal, the Son and the Damodar is first towards north and east and then westwards after the Vindhyan- Kaimur range. South of the Satpura Maikala line, the general slope of the land is to the east and the southeast. However, at its western extremity, the slope is quite steep towards the Arabian sea.

The plateau has remained above the sea level for a large part of the geological history and this has facilitated the sub aerial processes to work incessantly. The plateau also has crustal fractures and faults which are an element of diversity in its geomorphology.

The various stages in the evolution of the Peninsula is clearly discernible in the erosional surfaces of Chhotanagpur, the dissected gneissic country of Bundelkhand, the Narmada-Son-Damodar Lineament, the hill ranges of Nilgiri and Annamalai-Palasu-Cardamom and the valleys of Godavari and Kaveri.

The Peninsular plateau is characterised by enormous geomorphological diversity. However, it can be conveniently grouped into five main physiographic regions.

1. The Central Highlands

The Central Highlands are a wide tract of hilly country that includes the Rajasthan uplands, the Madhya Bharat Pathar, the Bundelkhand uplands and the Malwa plateau bounded by the Aravalli range on the West and the Satpura range on the South. The Satpura separates the Great Plains from the Peninsular plateau.

The Aravalli Range is one of the oldest mountains that runs for about 700 kms. from Delhi in a northeast to southwest direction through Rajasthan into northern Gujarat. The general elevation is only 400-600 m. although parts of this range lie well above 1000 m. Near Delhi, it has been reduced almost to the level of the alluvial plain. Nevertheless, it still retains its rocky character and is known as the *Delhi ridge*. Further

north, it continues up to Haridwar but is buried under the alluvium of the Great plains At the southern end it has been much more dissected and only few scattered buttes rising hardly above 60 m. are all, that remains of the Aravalli. However, the southern portion is more continuous and rises to over 900 m. south of Delhi, a long narrow ridge of hogback type extends for about 70 kms. from Sohna to Ramgarh rising to a maximum height of 404 kms. It widens out southwards in a fan like form south of Alwar. Here the topography consists of hogback quartzitic ridges, synclinal valleys and erosional valleys carved out of phyllitic rocks giving rise to a ridge and valley type of topography In the past, the entire length of the chain was a complete barrier to all kinds of movement from west to east. Today, however, the barrier effect is felt only in the central and southern parts. In the north, many wide water gaps run transverse to the range as far south as the Sabarmati river facilitating traffic. However, south of Bewar all the movements are restricted to four passes the Barr, the Pipli Ghat, the Dewair and the Desuri.

22

of pronounced strike ridge rising to 500 m. while the western part is a jumbled mass of hills and ridges of still higher elevation. Guru Shikhar (1722 m) on the Abu hills is the highest peak of the Aravalli and Mt. Abu (1158 m.) is the only hill station of Rajasthan.

The Rajasthan uplands and the East Rajasthan uplands, drained by the Banas and its tributaries, lie to the east of the Aravalli. They are 250 to 500 m. high and consist mainly of ancient crystalline rocks. The Madhya Bharat Pathar towards east is a plateau with rock surface made up mainly of the ancient Vindhyan sediments through which Chambal river has cut deep and wide valley and has formed **ravines** and **badlands**.

Dissected

Further east, lies the Bundelkhand upland presenting an old erosional surface cut out from granitic and gneissic rocks of Bundelkhand and sloping towards northeast These surfaces with an average elevation of 100 m., 150 m. and 300 m. cover almost the whole of the region though individual mesas and buttes rise here and there. The Bundelkhand uplands merge imperceptibly with the Great plains. Then the landscape changes. Buttes of granite and sandstone, long narrow serrated ridges of quartz reefs and **trap dykes** diversify the topography.

The Malwa plateau lies towards the southwest. It is a large physiographic feature made up mostly of lavas. It has rolling surfaces and flat topped hills dissected by several rivers of which the Chambal, Betwa and the Parbati are important. South of the Bundelkhand upland, and east of the Malwa plateau, the Vindhyan scarpland forms a series of tablelands separated from each other by a prominent sandstone scarp trending east-west. It's structure in its simplest form is that of a flat topped syncline. The strong sandstones of the Kaimur, Rewa and the Bhander series of the Vindhyan group are the principal scarp makers and also form the surface of the three constituent plateaus descending in steps from west to east. All the three plateaus are limited in the south by a great escarpment locally known as the *Kaimur hills*. In the north similar scarps separate them from adjacent lowlands. Another series of transverse scarps trending north-south separate one plateau from the another. The plateau surface near the scarp is highly dissected and it is highly noticeable in the Bhander plateau. Streams flowing over the northern scarps of the Rewa plateau have formed rapids and waterfalls and the Tons, the largest of them have formed a gap separating Vindhyachal from the Mirzapur hills.

The Vindhyan range flanking the Narmada-Son rift in its north is an escarpment trending east-west. It varies in character and height depending on the structure and lithology of the underlying rocks. The general elevation of the Vindhyan hills is about 300 to 650 m. The western part of the range is chiefly composed of basalt. The peneplained topography of the Vindhyan rocks was subsequently buried under lava flow and is now in the process of being exhumed. Near Hoshangabad, the Vindhyan mountains come very close to the Narmada river and present a terraced slope built of hard sandstones alternating with shales. The Kaimur range on the eastern portion of the Vindhyan mountain is the most pronounced scarp in India developed on sandstones and limestones and is nowhere breached by any large stream.

2. The Deccan Plateau

The Deccan plateau is a vast territory occupying the major part of the Peninsula extending from the Satpura-Maikala ranges in the north through the Maharashtra plateau to the Telangana and the Karnataka plateaus on the south. The Western Ghats occupy most of the Maharashtra plateau, while Archaean crystallines are spread over the rest of the Deccan.

The Satpura range lies between the valley of Narmada in the north and the Tapti in the south. It commences in the west from the Rajpipala Hills through the Mahadeo Hills to the Maikala ranges. Most of the hills are occupied by the Deccan Trap and rise to an elevation of 900 to 1000 m. The two highest peaks of the Satpura are the Astamba Dongar (1325m.) and Dhupgarh (1350m.).

The Satpura widens considerably in the central part. This part is bordered to the north by the Mahadeo hills and to the south by the Gawaligarh hills. The Satpura forms a series of scarped plateaus to the north at an elevation of 600-900 m. The steep sided Deccan Trap block in the western part of the Satpura comes down to 360m at Khandwa-urhanpur forming a gap through which the Narmada may have flowed along what is now the Tapti River. The Tapti is the only major stream to arise from in the Mahadev hills rising from a spring near Multai (*see Chapter-3, Drainage*).

Nearly the whole of the Maharashtra plateau is formed of plateau basalt which has given rise to rolling plains with intervening shallow valleys. Flanking each of the three river valleys of the Godavari, Bhima and the Krishna, there are flat topped but steep sided low hills. granite & gneis

Unlike the Maharashtra plateau, which is made of Deccan Basalt, the plateaus of Andhra Pradesh and Karnataka are carved out of Archaean gneissic rocks. The Godavari divides the Telangana plateau into two sections. The northern section is bounded on the north by east flowing Wardha and on the east by south flowing Pranhita. The surface of the plateau is dotted with low hills and shallow depressions. The twin city of Hyderabad-Secunderabad is located in such a depression.

The northern portion of the Karnataka plateau is drained by the Krishna and its tributaries- the Ghatprabha and the Malprabha. The Mysore plateau is the loftiest and most well defined plateau in South India. The regional slope is to the east but the northern portion has developed a northerly slope. It is bounded on the west by the Sahyadris and to the east by the Eastern Ghat. Physiographically, the Mysore plateau can be divided into two sections, *Malnad* and *Maidan*. The *Malnad* portion is a hilly area bordering the Sahyadri having an average width of 35 kms. and an average elevation of 1000 m. It is dissected into steep hills and deep valleys and covered with dense forests. The highest is the Bababudan group. The *Maidan* is an area of rolling plains with low granitic hills.

3. The Eastern Plateau

The Eastern plateau has a much more varied topography than the Deccan. This part of the Peninsular plateau consists of the Baghelkhand plateau, Chhotanagpur plateau, Mahanadi basin and Dandkaranya The eastern part of Satpura is known as the Maikala plateau It is bordered on the east by a line of eastward facing escarpment, the Maikala range This
knot and th

East of the Maikala plateau and north of Mahanadi basin is the Baghelkhand plateau. The Baghelkhand plateau is bounded by the Son river on the north, and to its south occur anticlinal hills and synclinal valleys of sandstones and limestones which appear to be remnants of an ancient mountain of the type of the Aravalli trending east-west parallel to the Son The topography is further diversified by flat granitic plateaus to the east of Gopad (a tributary of Son) with broad undulations and basins of the Gondwana age in the south The Singrauli basin is considerably dissected.

The Chhotanagpur plateau has three major levels of which the Ranchi plateau on granite-gneiss is the largest. Rounded hills of massive granite **(exfoliation domes)** and slightly elevated terraces of older flood plains mark the topography of Ranchi plateau

Apart from these low hills, the surface otherwise is quite flat like a peneplain. The Ranchi plateau is deeply dissected around its edges giving rise to steep escarpments locally known as ghats. A number of waterfalls including the Hundru mark the breaks in the thalwegs of the **Subarnarekha** and other streams crossing these scarps. To the west of the Chhotanagpur plateau is the Damodar which drains the important Gondwana coal basins

North of the Ranchi plateau occurs a group of plateaus and hills including Hazaribagh and Koderma representing peneplains at various stages of uplift and dissection They are flat in their outward edges because of the massive character of the country rock granite-gneiss. northeast of the Koderma plateau is bold short quartzitic ridges which alternate with valleys carved out of schists giving rise to topographic feature similar to that of Appalachian mountains. A group of higher plateaus, the Netarhat and the Jashpur Pats overlook the Ranchi plateau on the west. These plateaus have flat laterite-capped summits known as *pats* which rise to over 1000 m and present steep scarps around their edges. These plateaus are mesa like and are supposed to be

the remnants of an older and more extensive peneplain largely destroyed in later cycles. They enclose a number of flat floored oval-shaped basins such as Chhechhari basin.

On the northeast, the Rajmahal hills demarcate the Chhotanagpur plateau. These hills are capped by lava flow of Jurassic age which are dissected on the northern edge to produce scarp like features.

The Peninsular plateau continues far eastward into northeast as the Shillong plateau, the gap between them is known as the Rajmahal-Garo gap The gap was formed due to downfaulting and the downfaulted portion is covered under thick deposits of alluvium brought by the Ganga and the Brahmaputra.

The Shillong plateau is a highly dissected tract extending over an area of 240 kms. long and 96 kms. wide with summit levels at 1000-1300 m. The plateau descends in a steep slope towards the Soorma valley. To the south of the Shillong hills occurs a typical granitic topography with rounded hills and shallow valleys. In the north, it is bounded by the Mikir and the Rengma hills.

The Garhjat hills in Orissa extend from southern border of the Ranchi plateau to almost the Mahanadi in the south. It is lower in elevation than the Ranchi plateau but having a much pronounced local relief. The Bonai, Keonjhar plateau and the Simlipal Massif are relics of an ancient landmass attaining heights over 1000 m They have been reportedly peneplained and uplifted.

The Mahanadi basin is a low lying tract surrounded on all sides by hills rising from 600 to 1000 m. The central part of the Mahanadi basin is named after Chhattisgarh Chhattisgarh is a region of remarkable uniformity in relief interposed between the Mikir and the Orissa hills. It is mainly drained by the Sheonath, a tributary of the Mahanadi. The terrain gradually rises southwards into the Bastar hills.

South of the Chhattisgarh basin is the Dandakaranya region. The Indravati flows in the middle of this region from east to west across three broad terraces - the highest is the Koraput plateau (1200 m.), the second terrace is well developed around Jagdalpur, westward to Chitrakoot where a fall has developed on the Indravati river. Below the fall the third terrace exists.

4. The Eastern Ghats

The Eastern Ghats are not really mountain ranges in the true sense of the term. They are highly broken and discontinuous running in fragmentary spurs and ranges down the east side of the Peninsula from the Mahanadi in Orissa to the Vaigai in Tamil Nadu The range is cut into various discontinuous blocks of hills by several large antecedent rivers flowing down towards the Bay of Bengal.

The Eastern Ghats exhibit a true mountainous character only between the Godavari and the Mahanadi with an average elevation of 920 m. North of the Mahandi it has several peaks above 1000 m. in height like the Meghsani, Thakurain, Gandhmardan and the Malayagiri. The highest peak is the Mahendragiri (1501 m.) after which the Eastern Ghats here are known by the same name. This mountainous tract, principally composed of Khondalites (after Khondmal hills) and charnockites, is locally known as *Maliyas* (highland) Besides Maliyas the Eastern Ghats also comprise the Madugula Konda range The general elevation of the Madugula Konda is higher than the Maliyas at 1100-1400 m; the most eminent summits are the Arma Konda (1643 m.), Gali Konda (1643 m) and the Sinkram Gutta (1620 m.). Its southern part, the Rampa hills is traversed by a narrow gorge of the Godavari This gorge is a clear evidence of the antecedent character of the Godavari

The Eastern Ghats appear as a continuous range only in the Cuddapah and Kurnool districts of Andhra Pradesh To the east of the Eastern Ghats there are two other groups of hills, the southern group is dominated by the Sheveroy Hills and the northern by the Javadi hills. Both of them are highly dissected

The other prominent ranges are the Nallamalai and the Velikonda. The arcuate Nallamalai range and the broken chain of the Velikonda ranges are of lower elevations (600-850 m.) at the southern end of Eastern Ghats The Nallamalai range runs parallel to the Coromandal Coast and changes its strike northwards alongwith the change in the direction of the coastline. Its southern part, the Palakonda range, is higher. The length of the Nallamalai from the Palnad basin in the north to the Tirupati hills in the south is about 430 kms and the elevation ranges from 900 to 1,100 m To the west of the Nallamalai is the wide Nandyal valley. To their south, the hills and plateaus attain very low altitudes only the Javadi and the Sheveroy hills, form two distinct features of 1000m general elevation between the Palar and the Kaveri valleys. The southernmost

limit of the Eastern ghats may be taken as the small isolated hills of Karandamala and Sirumala lying between the Kaveri and Vaigai Valleys.

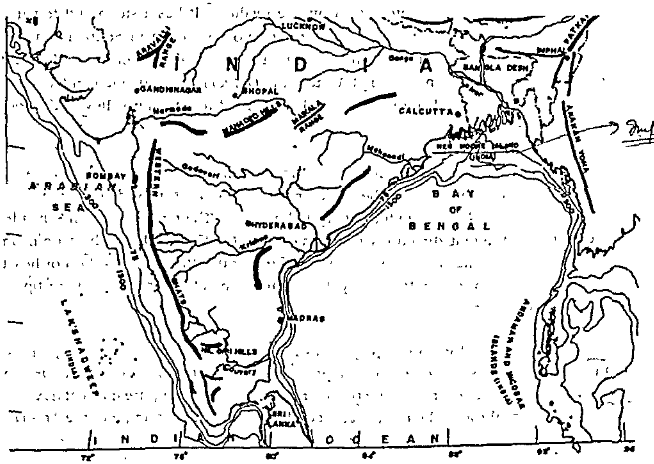
A fairly wide belt of hilly country lies at the foot of the Eastern Ghats in Chennai. This place gives one of the best examples of **pediplains** in India. All the east-flowing rivers from the Vaigai in the south to the Palar in the north have to cross this upland before entering into the east Coastal plains.

pene plains & pediplai

5. *The Western Ghats*

The Western Ghats also known as the *Sahyadris* form the western end of the Peninsular plateau running from Khandesh, south of the Tapti to Kanya Kumari for 1600 kms. (Fig.2.6). They have a general altitude of 900-1100 metres but occasionally rise to 1600m.

Fig.2.6. The ranges of the Peninsula



The northern section of the Ghats is made up of horizontal sheets of lava which have produced a typical trappean like landscape, the eastern side descending in steps one below the other and forming a formidable wall like feature on the western side overlooking the western coastal plain. The Western Ghats reach elevations upto 1200 m but some of the peaks attain greater height such as Kalsubai (1646 m.) near Igatpuri and Salhar (1567 m.). A large number of *en echelon faults* strike northwest-southwest are found along the trend of the Ghats. The Thalaghat and the Bhorghat are two important passes in this range.

South of 16° N latitude, the Sahyadris are more rugged and run closer to the coast. The western scarp is considerably dissected by headward erosion of the west flowing streams The general elevation in this part of the ghats reach 800-1000 m. but the highest peak here is the Vavul Mala which rise to 2339 m. The Nilgiris is the meeting point of the Western ghats with the Eastern Ghats. Here the Western Ghats again rise abruptly to over 2000 m above which are two of its highest peaks, the Doda Betta (2637m.) and the Makurti (2554m) The southwestern part, named the Kunda is more hilly and is traversed by bold ranges and intersected by deep valleys. It has a steep cliff towards the Malabar plains on the west. There is perhaps no landscape in South India that surpasses this enormous escarpment in grandeur. The rest of the Nilgiri has a different topography altogether having undulating terrain. *Ootacmund* (Udhagamandalam), a popular hill station in South India, is located in a broad undulating valley at the foot of the Doda Betta.

The southern portion of the Ghats is separated from the main Sahyadri Range by Palghat gap which is believed to be an abandoned valley of an old river. South of Palghat occur several flat topped hills of crystalline rocks. The ranges of south Sahyadri radiate in three different directions from Anai Mudi (2695 m.), the highest point in southern India; the ranges are the Anaimalai to the north, the Palini to the northeast and the Cardamom to the south. Finally, the Ghats terminate near the southern tip of India at Kanya Kumari.

The Western Ghats form a perfect watershed. The rivers flowing eastward journey all through the Peninsula before they empty themselves in the Bay of Bengal. On the Western face there are several indentations formed by swift flowing streams that traverse the short distance through the narrow coastal plain before discharging into the Arabian Sea.

The Great Plains

In front of the Himalayas lies the Great Plains of India which are spread over an area of 777, 000 kms. They include the Sindh plains, the Punjab Haryana plains, the desert of Rajasthan, the Ganga plains of U. P., Bihar and West Bengal and the Brahmaputra valley of Assam. The central part have been built up by the Ganga and its tributaries The Punjab plains occupy the western part of the Great Plains where tributaries of the Indus flow in a southwesterly direction The southern part of the Punjab have arid condition which continue southward towards west Rajasthan where the arid conditions get accentuated. West Rajasthan was originally a part of Indo-Gangetic plains but today it is *passing through a different landscape cycle*. This section of the Great Plains forms a distinctive region called the Western Arid Plain The Brahmaputra region has been formed by Ganga and its tributaries. The Great Plain extends for 3200 kms between the mouths of Ganga and Indus all along the foot of the mountains with a width varying between 150-300 kms. The Plain is narrowest in Assam where it is only 90-100 kms. wide but it widens to a maximum of 400 kms. in Bengal, it expands to about 500 kms. in western India and the adjoining Pak regions.

The Great Plains are an alluvium filled trough whose depth varies from place to place. In other words, they are a classical example of an aggradational plain which resulted from an infilling of initial depression by the incessant work of the Himalayan rivers. The maximum depth recorded so far is about 2000 metres. There is no uniformity in the thickness of the alluvium either in the Ganga or the Indus basins,the indus basin being much shallower than the Ganga basin.

It is not true that the Great Plain is a region of monotonous relief. Of course, as far as the diversity of features is concerned there is no comparison between the Himalayan mountains and the plains or even between the Plain and the Peninsula. However, the plain has its own diversity. Generally, the Plain is recognised as consisting of four division each characterised by important differences in surface relief. They are the Bhabar, Terai, Bhangar and the Khadar.

The Bhabar

The *Bhabar* lies all along the foot of the Siwaliks running from the Indus to the Tista. This **piedmont plain** is a pebble studded zone intermixed with finer and extremely pervious detritus so that the smaller Himalayan river disappear underground

on reaching this region The pebble beds are usually parallel to the slope of the river beds but there are some exceptions. The Bhabar is generally a narrow belt only 8 to 16 kms in width

The Terai

The *Terai* (Hindi *'Tar'-Wet*) belt is marked by re-emergence of the streams which have lost themselves in the Bhabar. Thus, it is a marshy tract and zone of excessive dampness with a thick growth of forests and a variety of wildlife.

The Bhangar

Most of the Great plains are composed of alluvium deposited during the Middle Pleistocene and recent geological time. The older alluvium is called the *bhangar* which forms higher ground in the **interfluve area** and forms **alluvial terraces** above the level of the floodplains. It is often impregnated with calcareous concretions known as *Kankar*

The Khadar

The younger alluvium of the flood plains of the numerous rivers is called the *Khadar* in Uttar Pradesh and the *bet* in Punjab. They form the low lying floodplains adjacent to river banks.

There are two main relief features on the Indian plain - **alluvial cones and fans and intercones** - the intervening slopes between two cones. Alluvial cones are found associated with all the Himalayan rivers except the Ghaghara. Simple cones have been formed by most of the Himalayan rivers except the Beas, Ravi, Mahananda and the Tista, all of which have formed composite cones. The Bihar plain offers one of the best examples of alluvial cones and intercones. Lying between the Himalayan foothills and the Ganga, the north Bihar plain is composed of three cones of the Gandak, Kosi and the Mahananda - Tista separated by intercones which have a reversed plan to that of cones. The size of the cones varies from river to river depending on the volume of water and the load carried by the river.

The regional slopes of the Great Plains are mainly in two directions, southeast and southwest, and the general shape conforms to the trends of the mountains lying north,

west and east. It is largely due to the influence of the Himalayas that the plains extend from west to the east. The regional slope is influenced by the underlying Aravallis in the west and by the buried Rajmahal - Garo gap in the east. The surface of the Great Plains is well above 200 m. in the Punjab plains while near the mouth of the Ganges, it is at tide level. This one factor has relieved the Great Plains of much of their monotony Thus, there exists differences in local relief over the entire extent of the plain from Sindh to Assam Each of the segments of the plain has acquired distinctive character of its own.

Sindh Plains

The Sindh Plains lie to the west of the Indus. It is one of the most homogenous physiographic unit, on the Earth having a total area of more than 50, 000 sq. kms The plain is mainly formed of *bhangar*. The northern part of it is a clay *pat* desert while the southern part is generally sandy to loamy and is dotted with many small lakes. To the east of the Indus, the relief is deltaic in nature. There are many remnants of the former river courses on the recently deposited alluvial sands and clays. These are called *dhoros*. Along the dry courses of these rivers there are many alkaline lakes which are locally called *dhands*. Towards the east, the Indus delta gradually merges into the Rann of Kachchh.

The Thal Desert

Between the Indus and the Jhelum-Chenab rivers lie the Thal Desert. The desert is also known as the desert of the Indus and its northern boundary is formed by the salt ranges. The northern portion is 80-90 kms. wide but narrows down to only 20 kms. at the southern end. It traverses for about 250 kms. from the north to the south covering an area of about 18,000 sq. kms. It is mostly a monotonous desert, only the central part is occupied by shifting sand dunes and the southern part is dotted by some oasis. The longitudinal depressions between the sand hills are known as the *pattis*.

The Punjab Plains

The Punjab-Haryana plains extend for about 640 kms. from northeast to southwest and cover an area of 1.75 lakh kms. The Aravalli Ranges extending up to Delhi and the ground swell running along the west bank of Yamuna farther north, form its eastern boundary. The altitude of the plain varies from 300 m. in the north to 200 m. in the

south The Punjab Haryana plain is drained by five rivers and the intervening area between the rivers is known as **doab.** The *doabs* of the five rivers have been united by the depositional process into a homogenous geomorphological unit. From east to west these doabs are as follows·

(i) Sindh Sagar doab between the Jhelum-Chenab and the Indus.

(ii) *Chajj* doab between the Chenab and the Jhelum

(iii) *Rechna* doab between the Ravi and the Chenab.

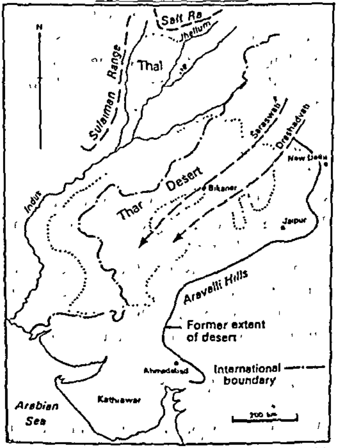
(iv) *Bari* doab between the Beas and the Ravi.

(v) Bist - Jalandhar doab lying between the Beas and the Sutlej

The mass of alluvium brought by five rivers has been broken by river courses which have carved for themselves broad flood plains of *Khadar* flanked by **bluffs** locally known as *dhaya.* These bluffs, somewhere as high as 3 metres or more, have been heavily **gullied** These type of features continue further eastwards.

The northern part of the Punjab-Haryana plain adjoining the Siwalik hills has witnessed intensive erosion leading to gully formation by a network of streams called *chhos.* These streams rearrange their deposits every year and the stream banks are so unstable that they go on shifting continuously.

Fig.2.7. The Thar Desert



The Thar Desert

The drier plains of the Punjab extend southward and merge imperceptibly into the arid plains of Rajasthan. The desert is about 650 kms. long and 250-350 kms wide occupying an area of some 2, 00, 000 sq. kms. This tract has a well defined boundary on the east marked by the Aravalli range (Fig. 2.7).

The desert forms an undulating plain. Its average elevation is about 325 m but the elevation drops to about 150 m. near the India-Pakistan border. This tract has two regional slopes; westward to the Indus valley and southwards to the Rann of Kachchh. A few rocky hills to the south of the great bend of the Luni rise even to about 1000 m west of Jaisalmer, the ground level falls to below 100 m. and the lower Luni valley is the most lowlying part of this region hardly rising about 20 m. The desert is crossed by short dried up streams. Its western portion lies in a piedmont depression in the Indus valley and its eastern part is located in an eroded section of the Indian plateau The eastern part of Thar is characterised by a complex of **aeolian** sand ridges alternating with outcrops of older bedrock alongwith innumerable depressions in the flat ground (**swale** and **ridge topography**).

The vast desert territory consists of two parts :

(i) the desert proper or the ***Marusthali***, fringed by

(ii) semi desert known as the ***Rajasthan Bagar*** which also contains some sand free land with steppe type of vegetation. The Marusthali is a wide expanse of sand 200-250 m. above the sea level containing sand dunes. It is devoid of any river. In general, the eastern part of the Marusthali is rocky; the western Marusthali is sand covered almost all over by shifting sand dunes locally known as the *dhrian* The main characteristics of western Marusthali are to be seen near Jaisalmer town which stands on a rocky plain. The Jaisalmer plain is traversed by short intermittent and discontinuous streams. To the north of Jaisalmer, a number of **playa lakes** called the Ranns occur in basins rimmed by scarps. They are characterised by centripetal drainage and remain dry for greater part of the year.

The eastern part of the Thar which forms a piedmont west of the Aravalli Range is a semi-arid plain called the *Rajasthan Bagar*. The Bagar has flat surface and in some parts it contains salt soaked playa lakes locally known as the *sar*. The Bagar is drained

by a number of short streams originating from the Aravalli and it also contains some sand hills The fertile tracts here are known as *rohi* Several large patches of rohi land occur in the northern and the central parts of the region. The Ganga plain at the northern end and the Godwar plain within the Luni basin at the southern end are agriculturally the most productive parts of the Bagar plain. The highest group of hills in western Rajasthan occurs in this region. Parts of the hilly region is buried under sand, though there are evidences which suggests that it represents a fluvial landscape carved out by former rivers and subsequently modified by the aeolian processes. *The tract north of the Luni is known as the Thali or sandy plain, it has immobile or stabilised sand dunes.* The commonest type of dune in the Thar desert is U-shaped parabolic dune. The mean height of the dunes range from about 8 m. in Jaipur and Sikar district to 31 m. in Barmer. There are relatively few simple **longitudinal dunes** (**Siefs**) locally known as the *bhits* and few **barachan dunes**. Within these sief dunes there are large number of depressions occupied by alkaline lakes locally called the *dands* or the *dhands* The Dhands are salt lakes or hollows, not more than three metres deep, elliptical in shape and aligned parallel to the ridges of the longitudinal sand dunes. They are numerous in the western part of the desert. Some dhands have no outlets to drain their water and they become huge evaporating pans.

The Ganga Plains

The Indo-Gangetic pl
y three transverse 'high'
Haridwar ridge, Faizabad ridge and the Munger - Saharsa ridge. Thus, from east to west he various units are

1. The Delhi - Haridwar Ridge
2. The Sharda Depression
3. The West Uttar Pradesh Shelf
4. The Faizabad Ridge
5. The Gandak Depression
6. The East Uttar Pradesh Shelf

7. The Munger - Saharsa Ridge

The Ganga plains lie in Uttar Pradesh, Bihar and West Bengal. It includes the Ganga-Yamuna Doab, Rohilkhand plains, Avadh plains, Bihar plains, the north Bengal plains and the Rarh plains. The plain has been formed by the alluvium brought down by the Yamuna, Ganga, Ghaghara and their tributaries aligned parallel to them. It is bounded on the north by the Siwaliks which forms a knife edge boundary whereas the southern boundary is formed by the Peninsula and is broken by its impenetration.

South of the Yamuna, the thin alluvial layer merges with the spurs of the plateau in the narrow floodplain of its tributaries the Chambal, Betwa and the Ken.

The *Ganga-Yamuna doab* is the largest doab. The general slope of the land is from north to south but there are many micro slopes. The old Bhangar alluvium of the doab has formed an upland that is quite distinct from the low Khadar. The intervening slopes which are quite pronounced with a relative variations of 15-30 metres in relief are locally known as the *khols*. There are marked differences in the development of the drainage channels and other relief features in the three sections of the alluvial mass. The khols have a variation of 8 to 15 metres along the Yamuna while in the case of the Ganga, this variation is of the order of 12 to 20 metres. However, the land is generally flattish as is evident from the variation in local relief that is only from 4-6 metres. Two distinct alluvial terraces both in the Ganga and the Yamuna Khadar are identified. They are flanked by two natural levees, of which the older one is more extensively eroded.

not by

Further, variations in the topography is introduced by the *bhur* aeolian deposits. The bhur forms a belt of undulating sandy uplands on the eastern bank of the Ganga in Muradabad and Bijnor.

East of the Ganga Yamuna Doab is a vast stretch of alluvial plains from the Himalayan foothills to the Ganges plains called as the Rohilkhand plains. It lies almost entirely in Uttar Pradesh covering about 35,000 sq. kms. The level of the land increases from 132 m. on the east to 274 m. on the west. The bhabar and the terai are well developed in this region.

Q: Does the slope a... of rivers ??

The Rohilkhand plains merge imperceptibly into the Avadh plains. It lies towards the north of the Ganga and is gently sloping eastwards. The Avadh plains is traversed by the Ghaghara. The numerous bars and channels indicate that the river is an aggrading river and constantly shifts its channels.

The Avadh plains end in Bihar plains. The Bihar plains have been narrowed down by the Rajmahal hills The two parts north and south of the Ganga are known as the North Bihar plain and the South Bihar plain, respectively.

The North Bihar plain is a land of rivers. The Ganga receives three major Himalayan rivers, the Ghaghara, Gandak and the Kosi and a large number of mountain streams on its left bank. The general slope of the plain is towards southeast in the western part and south in the eastern part A long line of marshes extends from a little east of Chapra to near Khagaria parallel to the Ganga, locally known as the *Caurs*. Some of these caurs are deep enough to contain water throughout the year (e.g., Kabar Tal). South of the caurs, the surface rises towards the Ganga.

South of the Ganga and west of the Rajmahal hills, are the South Bihar plains which increase to a maximum width of 120 kms Like the North Bihar plains, it also contains *Jala* near Patna and *tal* farther east of Mokama.

The plains of North Bengal extending from the foot of the eastern Himalaya to the northern limit of the Bengal basin is formed by the detritus being brought from a number of powerful streams like the Tista, Jaldhaka and the Torsa and its western fringe, known as *Western Duars*, is most typical. South of the Duars, the plains are more flattish and get waterlogged during the rains.

The Bengal basin includes most of West Bengal and Bangladesh. It is quite flat. The major portion of the Bengal basin is occupied by the Ganga delta. The delta has its seaward face more influenced by the tidal activity than by the waves with the result that the indented coastline has a maze of sandbanks, **mud flats**, mangrove swamps, islands and **forelands**.

Although not a part of the delta, the lowland to the west of the Bhagirathi is equally flat and is called the *Rarh plain*. The natural levees strengthened by artificial embankment is a characteristic feature. **Dead arms, deferred junctions** or the *bhils* add to the variety of the landscape.

The Brahmaputra plain or the Assam plain is rarely more than 80 kms. broad surrounded by high mountains on all sides except on the west. The general level of the valley varies from the valley slopes towards the southwest draining into the Bay of Bengal. The gradient is quite low and is characterised by numerous riverine islands. Numerous isolated hillocks rise abruptly from the general level of the plain.

Randi has made gorges

(5) Tons has made waterfalls on the Rewa plateau.

i.e. dissected surface.

(6) Subarnarekha has made waterfall Hundru on Ranchi plateau

(7) Palghat gap created by Peninsular rivers.

The Coastal Plains

valleys flat

The Peninsular plateau is flanked by the coastal plain of varied width extending from Kachchh in the west to Orissa in the east. These coasts are of **longitudinal Pacific type.**

faulted Dissected eg. → Jog waterfalls

(4) W. Ghats dissected by W. flowing rivers by Headward erosion

(1) Delta formation → 100 done Pen. ...

(2) Estuaries

(3) Gujarat plains

East Coast

The steep scarp faces

The East coast of India starts from the edge of the Ganga delta and runs to the southernmost tip of India, at Kanyakumari facing the Bay of Bengal. The coast is mostly of **emergent type,** *i.e., it is regular in outline* and is characterised by **offshore bars, fine sea beaches, sand ridges and lagoons.** It extends from Cape Comorin northwards to the united deltas of Krishna and Godavari for 1100 kms. with an average width of 100 to 130 kms. Farther north, the hills come down almost to the coast. North of Berhampur, the east coastal plain widens again and extend to the Chilka lake, the delta of Mahanadi and Baleshwar (Balasore) coastal plain where they merge into the Ganga deltaic plains. From north to south the coastal plains are known as the Utkal, Andhra and the Tamil Nadu plains.

The Utkal plains extend for about 400 kms. from a little north of the Subarnarekha to a little south of the Rushikulya river. They include the Mahanadi delta with Cuttack at its head. South of the Mahanadi delta is the Chilka lake Its origin is due to the formation of a **bay mouth bar.**

The Andhra plains stretch from the southern limits of the Utkal plains to the Pulicat lake about 40 kms. north of Chennai. Their elevation near the coast ranges from 5 to 50m. The Godavari and the Krishna flowing through this region have formed deltas. Between the two deltas lies the Kolleru lake. The Pulicat lake has been barred by a long **sand spit** now called the Sriharikota islands. The lagoon is about 60 kms. long and about 60 kms. broad in the widest part. It is dotted with several large islands.

The Tamil Nadu plains is about 675 kms. in length with an average width of 100 kms. The Kaveri delta is the most important physiographic unit in this region. The Kaveri river divides the delta into two channels. The islands Srisailam, Srirangapattam and Sivasamudram are found in the Kaveri delta.

The eastern continental margin is of narrow width, only 30-60 kms. wide between the deltas of the Mahanadi and the Kaveri. This shelf is advancing seaward at the rate of one kilometre in 25 years because of sediments brought about by the rivers.

The Western Coast

The plains of West Coast, are confined to a narrow zone the width ranging from 10 to 25 kms. It extends for about 1500 kms. in length from Surat in the north to Kanyakumari in the South The Western Coast is divided into three sections - the Kathiawar coast till Daman and Diu, the Konkan coast between Daman and Goa and the Malabar coast south of Goa The West Coastal plain is a **fault coast.** Several projections into the sea have formed open bays. South of the Indus delta, is the Kathiawar coast (Peninsula) But for it the Western coastline runs straight from the Gujarat plains to the extreme south. This straight looking coast is quite indented marked by a large number of **coves** (small sheltered recess in the coast) and **creeks** (small tidal inlets or estuaries of small streams)

The most important physiographic feature of the Kachchh Peninsula is sandy plains and bare rocky hills The coasts are fringed with sand dunes. Behind these, and particularly in the south, fertile plains extend parallel to the coast with an average width of 50 kms , the shores of Kathiawar are slightly raised above the sea level. East of Kathiawar lie the plains of Gujarat.

→ Work done by the Peninsular rivers.

The Gujarat plains are built up mainly of alluvium of the Sabarmati, Mahi, Narmada and the Tapti, all of which have formed large **estuaries**. The regional slope is to the west and the greater part of the plains lie below 150 m The northern part of the plains is drained by the Banas and the Saraswati into the Gulf of Cambay. Elsewhere the plain is drained by the Sabarmati, Mahi, Narmada and the Tapti. The banks of the lower reaches of the Mahi are dissected into ravines. Near the coast, wind blown Loess covers a greater part of this region. Near the western limit of the Gujarat plains, a series of saline marshes occur which are subjected to overflow at high tides.

The Konkan coast stretches from Daman to Goa for a distance of 500 kms. It is narrow and has typical coastal features. The coastline in general is cliffy. The submerged coasts are indicative of rise in the sea level. Raised terraces either in the form of pure coral reef or as impure incoherent calcareous rocks full of shells and corals known as **littoral concrete** occur in the esplanade islands of the Mumbai city. The northern

portion of the Konkan coast is drained by the Vaitarna river which provided means of earliest trade between the sea and north Deccan. The coastal plain is dotted with flat topped hills.

The Malabar coast runs for about 725 kms. from north to south In the northern part in Karnataka, transverse flat topped spurs come down almost to the shoreline from the edge of the plateau. The plain is nowhere more than 24 kms wide and is often only 8 kms The plains in Kerala are much wider and less hilly with an average width of 25 kms. and ranging from 10 to 30 kms. in elevation. It is only on the Malabar coast that there are a number of lakes, lagoons and backwaters locally called the *Kayals* The largest of such backwater is the Vembnad lake. It is 80 kms long and 5-10 kms. wide, enclosed by a 55 kms long spit. Some unique mud banks have been located between Cochin and Alleppy in the continental shelf off Vembnad lake. They are the modern analogues of an ancient hydrocarbon generating environment.

The western continental margin is much broader than the eastern counterpart. It is only 40 kms. on the southern ends but gradually widens to almost 330 kms. south of the Kathiawar Peninsula. A large platform rises on the shelf some 125 kms. into the sea fronting the Ratnagiri coast.

Table 2.1 Difference between Western and Eastern Coast

EAST COAST	WEST COAST
Much broader	Narrower
Smooth outline	Dissected outline with many indentation
Occurrence of deltas	Occurrence of Estuaries
Runs in wide curves	Runs more or less straight
More dry	Wetter, abundant rainfall
Contains shifting sand dunes	Dunes and stretches of saline soils

The Oceanic Islands

There are many types of islands occurring around the mainland - deltaic, coral and volcanic

The deltaic islands have been formed by outward building of deltas by nearshore deposition of river horne sediments aided by wave deposition. There are few islands off the east coast, all of which have depositional features e g , on the mouth of Dhamra river, north of the Mahanadi delta and on the mouth of Chilka lake and numerous islands on the mouth of the Ganges.

In contrast, practically all along the west coast are numerous small islands, generally rocky, reflecting the lithology of the nearby shore. In the Khambhat area, on the estuary of the Narmada occur some depositional islands, the largest of which is a 16 kms long island known as Aliabet Off the south coast of Saurashtra there are two prominent islands. One of which is Diu. The small islands in the Gulf of Kachchh are extensions of the Deccan basalt Most of the islands in the Rann of Kachchh are small and rocky but the larger ones are the Pachham Khadir and Bela island. The two major islands of Mumbai on the west and Sriharikota on the east have now become part of the mainland.

The Pemban Island and the Mannar are the remnants of the ancient land link and are now connected by Adam's bridge.

The Andaman and Nicobar islands are the submerged peaks of ridges continuous with the Arakan Yoma mountain ranges. A parallel chain of islands to the east of Andaman are almost entirely submerged except for the volcanic islands of Narcondam and Barren and which rise at pinnacles above. The Barren Island is the only active volcano in India.

The Lakshwadeep which literally means one lakh islands are widely scattered in the Arabian Sea 200-250 kms. off the coast of Malabar. There are two sub groups. The islands north of eleventh parallel are collectively known as Amindivi Islands which includes Amini, Bitra, Chetlat, Kadmat, Keltan and a few tiny atolls, while those occurring south of it are Kavarathi, Cheriyan, Androth Pitti, Agatti, Kalpeni and several small islets together designated are Cannanore Islands. Minicoy is an isolated island 250 kms. south of Kavarathi

Physiographic Regionalisation

India may be divided into the following physiographic regions and sub-regions

I The Himalayas and the mountains of the northeast. Himalayas are subdivided into

(a) Western (b) Central (c) Eastern.

(a) Western Himalayas are further divided into

(i) Kashmir Himalayas (ii) Punjab (iii) Kumaon.

(b) Central Himalayas lie in Nepal.

(c) Eastern Himalayas are further divided into

(i) Bhutan, Sikkim and Darjeeling Himalayas

(ii) Arunachal Pradesh except Tirap district.

II. **Great Plains** are subdivided into

(a) Western Plains (b) Northern Plains (c) Eastern Plains

(a) Western plains further divided into

(i) Marusthali (ii) Rajasthan Bagar.

(b) Northern Plains are further divided into

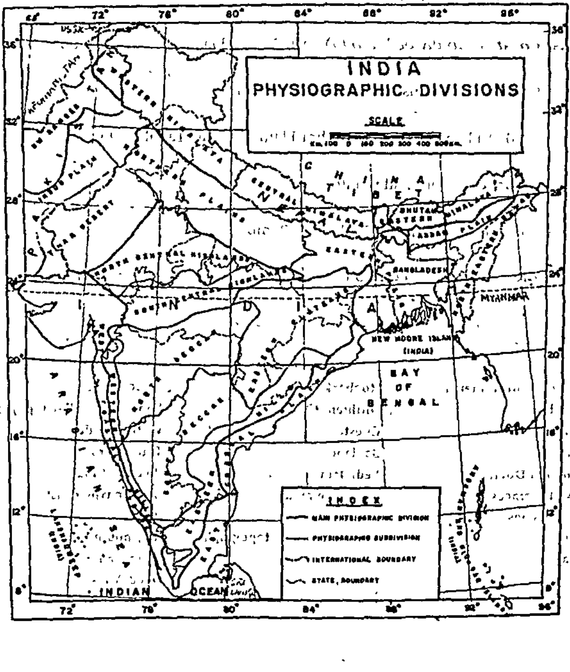
(i) Punjab Plains (ii) Ganga - Yamuna Doab.

(iii) Rohilkhand Plains and (iv) Avadh Plains.

(c) The Eastern Plains are further divided into

(i) North Bihar (ii) South Bihar and (iii) Bengal Plains

Fig.2.8. The major Physiographic divisions of India



(e) Eastern Hills are further divided into

(i) Eastern Ghats north (ii) Eastern Ghats south

(iii) Tamil Nadu Uplands.

(V) **East Coast** is sub-divided into (a) East Coastal Plains (b) Eastern Continental Shelf

(a) East Coastal Plains are further divided into

(i) Utkal Plains (ii) Andhra Plains (iii) Tamil Nadu Plains.

(VI) **West Coast** are subdivided into

(a) Kachchh Peninsula (b) Kathiawar Peninsula.

(VII) **Islands** are subdivided into (a) Bay Islands (b) Arabian Sea Islands.

Important Words

Epeirogenic Movements	Hogback	Synclinorium
Orthoclinal	Diffluent Glacier	Range and Valley topography
Centripetal drainage	Cuesta	Water Divide
Ravines	Badlands	Trap Dykes
Exfoliation Domes	Pediplain	Piedmont Plain
Alluvial Terraces	Interfluve area	Pacific type coast
Alluvial cones	Intercones	Bluffs
Gullies	Swale and Ridge topography	Baymouth Bar
Playa lakes	Parabolic dunes	Barachan
Mud Flats	Creeks	Dead Arms

3

DRAINAGE

Introduction

The drainage of India has evolved and adjusted itself with the evolution of the three physiographic units-the Himalayas, Peninsular plateau and the Indo Gangetic plain On the basis of the origin, the drainage system in India can be broadly divided into two categories: (i) The Himalayan rivers, and (ii) The Peninsular rivers

The Himalayan Drainage

The Himalayan rivers belong to the three principal systems-the Indus, the Ganga and the Brahmaputra. These three rivers have evolved through a long and fluctuating history. These rivers originate from almost the same region within few kilometres of each other separated by water divides. They first flow parallel to the main axis of the mountains in longitudinal troughs. Then they take a sudden bend towards the south cutting through the massive mountain chain to reach the north Indian plains. In the process, they have carved out deep V-shaped valleys. This is well exhibited by gorges of Indus, and the Brahmaputra. transverse gorges

These rivers have maintained their original course and direction by deepening their valleys simultaneously while the uplift of the mountains was in progress. Thus, they have got themselves entrenched forming deep valleys and gorges. These rivers which are older than the mountains themselves are called **antecedent rivers.** The gorges in the Himalayan ranges are thus not the result of headward erosion as in case of Peninsular rivers. The Indus has cut through a cover of 5000 m. of rock creating I shaped valley and then stepped valley. The Nanga Parbat rises steeply to 8125 m. within a few kilometres of the channel This difference in height is due to the antecedent

character of the river accentuated by upliftment only recently. The Sutlej carves out a similar transverse gorge 1800 m -2000 m. deep at Shipki. The Kali Gandak flows only at an elevation of 1200 m. at Dana between the Dhaulagiri (8172 m.) and the Annapurna (8078 m) only 55 kms apart, making it the steepest valley in the world. The bed level of the Arun at 1800 m. lies between the ranges on which Everest, Makalu and Kanchenjunga are situated

Except where the rivers cut across the ranges, the course of most of the Himalayan rivers are controlled by the strike and structure of the mountains, for example, Indus flows in a northwest direction through a strike valley between the higher Himalaya and turns southwards near Gilgit between two ranges which formed a natural divide before their uplift Tsangpo rising in the same area flows towards east through the depression in the suture zone The sudden change in its direction towards south around Namcha Barwa is controlled by the eastern syntaxis in a similar manner to that of Indus whose course is controlled by the western syntaxis. From Garhwal to Arunachal Pradesh, the rivers flow down the southward slopes and receive their tributaries which follow the east - west general strike of the hills In both the cases the direction is controlled by a combination of strike and structure aided sometimes by faults.

Evolution of the Himalayan drainage

The evolution of the Himalayan drainage can be deciphered in the piedmont deposits of the Siwalik which runs from one end of the Himalaya to another. These deposits are formed of boulder, conglomerate, sands and clays. These deposits are said to have been laid down by a mighty stream. This stream variously named as "*Siwalik*" or "*Indo Brahm*" traversed the entire longitudinal extent of the Himalayas from Assam to Punjab and from here it took a southerly course and finally emptied into a gulf which occupied parts of the Sindh and the Lower Punjab during Miocene period. This stream brought enormous amount of debris from the main Himalayan range in recent geological time, ranging in age from middle Miocene to Pliocene and deposited it at a continuous rate along the base of the mountains The stream is supposed to have carried the combined flow of the Himalayan affluent stream before draining into the Arabian Sea. The thickness and the extent of the Siwalik strata is a testimony to this task having been performed by this massive stream.

Later on the stream dismembered into:

(a) the Indus,

(b) the five tributaries of Indus in the Punjab,

(c) the Ganga and its Himalayan tributaries,

(d) the stretch of the Brahmaputra in Assam and its Himalayan tributaries

This splitting may have been caused either by the upliftment of the western Himalayas and the Potwar plateau in the Pleistocene or due to river capture which caused the drainage direction to be reversed. The upliftment caused the Assam-Punjab stretch of the Indo Brahm to flow from southeast - northwest to southeast direction

Two different rivers or two branches of the same river emptying into the Bay of Bengal cut back and beheaded this Indo Brahm, the eastern part gradually capturing the portion lying between the Yamuna and Assam. Meanwhile the Indo Brahm was being reduced further by the gradual capture of the portion lying between the Yamuna and the Jhelum by its own tributaries. The Attock portion of the present Indus was a tributary of the Indo Brahm which at an early period cut back its way into Kashmir where it captured the upper waters of a large river, that flowed northwestward either into the Oxus river or curved southwestward into eastern Afghanistan.

The Yamuna which had previously a southwesterly course and was possibly a tributary of the Indus was captured by the Ganga which took a southerly course.

Many evidences can be cited which shows that the river system evolved from a single river:

1 The enormous thickness of Siwalik deposits.

2 The V shaped valleys in the upper courses and the antecedent nature of the rivers

3. Similarity in the constituent rocks of the Indo-Gangetic plain (which are alluvial formations) with that of Siwalik formations.

4. Similarity between the fishes of the Indus and the Ganga system. This similarity would not have been there without their being joined together.

This theory, however, is not universally accepted. It has been criticised on many grounds

1 It is not necessary to visualise a stream of the size of the Indo Brahm or the Siwalik flowing all along the longitudinal extent of the Himalaya to explain the vast thickness of alluvial deposits consisting of boulder, conglomerate, sand, shale and clay These deposits may have been formed by the coalescence of many alluvial fans which were formed from numerous streams descending into the plains and debauching their load

2 The evidence furnished by the depositional history in the Ganga delta and in Assam does not fit well into this concept The Rajmahal Garo gap deposits should have been laid down over a much longer period of time than that suggested by the authors of the Indo Brahm theory.

In all probability the Rajmahal gap was formed during the second upheaval of the Himalayas, i e , just before the start of Siwalik sedimentation. A westerly flowing river could not have existed in the eastern Himalayan region because such a river would have found a ready exit into the Bay of Bengal through the Rajmahal gap.

3 The source of the river was close to an estuary as evidenced by Tipam sandstones of Assam and this poses serious difficulty to the acceptance of this theory.

An alternative explanation was put forward Protagonists of this theory, the so called **Multiple river theory**, found it difficult to accept the existence of a huge river on geological and physiographical grounds.

The Eocene sea extended up to Sind, Rajasthan and from the Punjab to Jammu and thereafter eastward to Lansdowne and Nainital, this was connected to Tethys. This is evidenced by existence of shallow water facies indicative of coast near Lawnsdowne. This limit also coincides with the eastern continuation of one of the ridges of the Aravalli Range which presumably acted as barrier. At the same time, another ridge extended from the Rajmahal Hills to the Shillong plateau (Rajmahal-Garo gap) which is now occupied by the Ganga-Brahmaputra basin The sea was broken by the first upheaval of the Himalayas to form an isolated basin in which sediments were deposited. The sediments show brackish water facies and later fresh water facies. In the next upheaval, a pronounced foredeep all along the southern border of the Himalayas was formed. This foredeep contained numerous uninterrupted lagoons in which flowed many

transverse streams from the Peninsula and the newly uplifted Himalayas. These streams brought sediments which later came to be known as Siwalik deposits. The outlet of this foredeep was through the Rajmahal - Garo gap into the Bay of Bengal and the Arabian Sea into the west. Later on the lagoons got dried up and the numerous transverse streams flowing from the Himalayan region formed what is now known as the Himalayan drainage.

The Himalayan Drainage System Not ⊗ Sir

The Himalayan region consist of three systems-the Indus, the Ganga and the Brahmaputra (Fig.3 1).

The Indus System

The Indus, originally called the Sindhu gave the country its name Alongwith its main tributaries, the Sutlej, Chenab, Jhelum and the Ravi, it forms a system of five main rivers after which the province of the Punjab is named. The Indus rises in the Tibetan plateau near Mansarovar lake from the springs of *Sengge Khabab* It enters the south eastern corner of Kashmir and flows in a northwest direction between the Laddakh and the Zaskar Ranges falling to some 4000 m. About 50 kms. from Skardu, it is joined by the Shyok at an elevation of about 2700 m., 40 kms downstream of Skardu at 2200 m it enters a 480 kms., long antecedent gorge. It takes a sharp southerly bend near Bunji and enters the plains near Talbala. After traversing mountain ranges in Kashmir the river takes a southward turn enters Pakistan and flows at the foot of the Nanga Parbat In Pakistan it is joined by the Kabul river from the west near Attock and it receives the accumulated waters of five eastern tributaries-the Panchanad near Mithankot. The river finally drains into the Arabian Sea near Karachi. The total length of Indus is 2880 kms of which 1114 kms. lie in India.

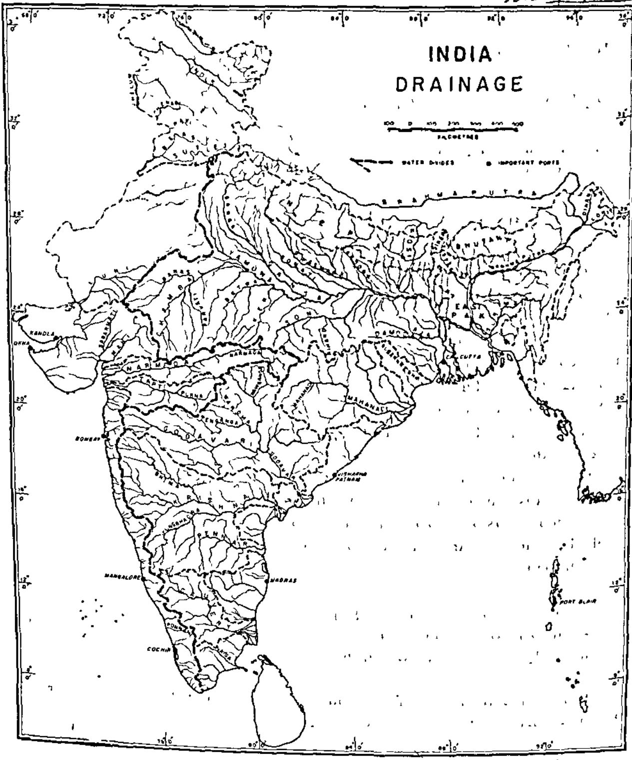
The Indus river system drains a large part of northwest India and most of the territory of Pakistan The total catchment area of the Indus river system is 11. 65 lakh sq. kms. of which 321,290 sq kms. lie within India.

The most important tributaries of Indus are Zaskar, Astar, Dras, Gilgit, Hunza, Kabul, Jhelum, Chenab, Ravi, Beas and Sutlej.

Water shed ⟺ drainage basin ⟺ water divid

Regional Planning is based upon mini- and mic-
ter sheds (may be also major). Also if on major watershed basin then how can it possibly be in Rajasthan.

Fig.3.1. The Drainage of India.



The Shyok is an important tributary of the Indus which flows all along its course parallel to the Indus for over 300 kms. before joining Indus near Kiris The principal tributary of the Shyok is the Nubra having its source in the Siachen.

The Kabul River like the Shyok is a right bank tributary of the Indus It rises in the southern Hindukush mountain near the Unnai Pass and breaches the Afghanistan-Pakistan boundary north Khyber pass before joining Indus at Attock.

The Sutlej (called *Langqen* in Tibet) rises from the Dharma pass on the Zaskar range, it joins another branch (*Lhangcbhen Kbabab*) coming from the east through the Mansarovar and Rakas lake within 80 kms. of the source of the Indus It takes a northwesterly course like the Indus on the Shipkila pass on the Tibet- Himachal Pradesh boundary and then turns southwestwards. In the Nari Khorsan province of Tibet, it has created an extraordinary deep canyon almost of the size of Grand Canyon Colorado up to 900 m. deep. Through its stretch the Sutlej cuts across the strike of the Himalayas as an antecedent stream through a straight steep walled gorge 1525 m - 3570 m. deep and 160 long between Shipki and north of Shimla. It descends into the plains at Ropar in the Punjab. Between Ropar and Mithankot a distance of 900 kms , the Sutlej has a low gradient as it flows over a plain of remarkably gentle topography

The Beas (*Vipasa* in Sanskrit) originates from Rohtang pass on the southern end of the Pir Panjal range close to the source of the Ravi. It enters a gorge 900 m deep at Larji where it takes a westerly course through the Siwalik hills emerging on the plains at Pong, thereafter it flows southwards to join Sutlej at Harike.

The Chenab (Sanskrit - *Asikini*) has both its headwaters the Chandra and the Bhaga rise in Lahul near the two ends of the pass over, the Bara Lachala (4871 m.) in Great Himalayan range. The rivers unite and then the Chandrabhaga flows through the Himachal Pradesh for about 100 kms. along a structural trough parallel to the Pir Panjal range. Entering Kashmir, it is known as Chenab. It takes a sharp southward bend at Kishtwar through a 290 kms. long gorge sometimes 1000 m. deep. All along its course, it receives tributaries with overhanging valleys It emerges on the plains at Riasi in Jammu and from here it turns to southwest through the plains of Pakistan Punjab until it unites at Panchnad with the Sutlej.

The Ravi (*Iravati* in Sanskrit) rises from the southern slopes of the Pir Panjal west of Mandi After following a course between the Sutlej and the Chenab it emerges on the plains at Madhopur

The Jhelum originates in the Pir Panjal near Banihal pass in Kashmir. It flows through the Vale of Kashmir passing through the Wular lake. At the head of the vale it flows in a westerly direction. Below Baramula, it flows in a deep valley with almost perpendicular walls. South of Muzaffarabad, it takes a sharp hairpin bend thereafter it forms the boundary between India and Pakistan for 170 kms. and emerges at the edge of the Potwar plateau near Mirpur

Evidences show that these rivers have continually changed their courses during the past For example, the Jhelum originally flowed in a southwest direction opposite to the present course This is evidenced by several tributaries which join it in a direction opposite to the present course. The Chenab flowed east of Multan in 1245 A.D. During this time, its course was filled by the Beas near Dipalpur. The Jhelum, Chenab and the Ravi met northeast of Multan and joined the Beas about 45 kms. south of it.

Table 3.1 The Indus and Ganga river system

River	Source	Total Length (kms.)	Drainage Area (sq. kms)	Important Tributaries
Indus after flowing for 709 kms in India, goes to Pakistan	Snow ranges of the Himalaya at an altitude of 5080 m. in Tibet near Mansarovar Lake	2,880 of which 1570 kms. (in India)	3,21,290	Zaskar, Astar, Dras, Shyok, Swat, Kurram, Shigar, Gilgit, Kabul, Jhelum, Chenab, Ravi, Beas and Sutlej
Chenab	At an elevation of 4,900 m. at Lahul	1,800 (in India)	26,755	
Ravi	Kulu hill of Himachal Pradesh	725	14,442	

Beas	Kulu hill at an elevation of 3,960 m. near Rohtang Pass	460	20,303	
Sutlej	At an elevation of 4,570 m. near Dharma Pass	1,050 (in India)	24,087	Beas joins at Harike
Ganga comprises two head-streams	(i) Alaknanda at an elevation of 7,800 m. (ii) Bhagirathi at an elevation of 6,600 m. Both join at Devprayag	2,525	8,61,404	Yamuna, Ram Ganga, Gandak, Ghaghara, Kosi, Burhi Gandak, Bagmati, Gomti, Son, Mahananda, Kamla, Damodar, Jalangi, Bhairab, Matabhanga-Gorai, Hooghly Confluence of Yamuna at Allahabad
Yamuna	West of the Ganga source at an elevation of 6,330 m. from a hot spring at Yamunotri.	1,300	3,59,000	Chambal, Betwa, Hindu, Ken, Sarda
Ram Ganga	Near Nainital, in the lower Himalaya at an elevation of 3,110 m.	696	32,412	joins the Ganga below Farukkhabad. Tributaries - Khoh, Gangan, Aril-Kosi, Deoha
Ghaghara	Rises east of the Ganga	1,080	1,27,950	Rapti, Sarda
Gandak	At an elevation of 7,620 m in the central Himalaya near Tibet.	425 (in India)	9,540 (in India)	In Nepal, it is known as Narayani. It joins Ganga at Patna. Total drainage: 45,800 sq. kms.

Burhi Gandak	Western slope of Sumesar Hills at an elevation of 330 m.	320	10,150	Joins Ganga at Munger (Bihar)
Kosi	From Tibet/Nepal.	730 (in India)	11,600	Kosi, Arun, Tamur. Total drainage: 74,500 sq. kms. Notorious for floods and hence known as "Sorrow of Bihar".
Gomti	About 3 kms. east of Pilibhit at 200 m. elevation.	940	30,437	Sai, Barma, Saryu, Chuha, Gachai, Jomki
Damodar	Rises in Chhotanagpur plateau (near Balumath) at an elevation of 1,366 m.	541	22,000	Gartus, Konar, Jamunia and Barakar. Once known as "sorrow of Bengal"
Son	Amarkantak			Joins Ganga at Maner near Patna. Tributaries-N. Koel & Punpun

Source Mamoria and M S Krishnan

The Ganga System

The Ganga has twin sources, the main one being the Gangotri glacier at Uttarkashi in Uttar Pradesh where it is called the Bhagirathi and the other being the Satapnath glacier northwest of Badrinath where it is called the Alaknanda. The two join at Devprayag to form the Ganga that emerges from the hills of Haridwar. At first, the river takes a southerly direction and then turns eastwards flowing through the plains of Uttar Pradesh, Bihar and West Bengal. In West Bengal it bifurcates into two branches, the Padma flowing into Bangladesh and the Bhagirathi known as the Hooghly in Bengal.

The catchment area of the Ganga basin including its southern tributaries that originate in the Vindhayan plateau is 10.86 lakh sq. kms. of which 8. 61 lakh sq kms. lies in India The important tributaries of the Ganga are the Yamuna, the Ramganga, the Ghaghara, the Gandak, the Bagmati, the Kosi and the Son.

The Yamuna has its source in the Himalaya; at the Yamunotri glacier on the Bandarpunch Peak in Garhwal, not very far from the origin of the Bhagirathi. It cuts across the Nag Tibba, the Mussorie and the Siwalik ranges and emerges on the plains above Paonta in Himachal Pradesh. (Lesser Himalayas)

In the plains upto Mathura the Yamuna takes a southerly course and from here it turns south east until it unites with the Ganga at Allahabad. It traverses a total of 1400 kms. from its sou formed part of the Indus system and joined ...ained directly into the Rann of Kutch, but finally it became a tributary of the Ganga because of tectonic disturbances

The Ghaghara, called the Karnali in western Nepal, originates near Gurla Mandhata Peak south of Mansarovar in Tibet. It first flows southeast and then south-southwest cutting across the higher Himalaya. It joins the Ganga near Chapra in Bihar

The Gandak rises at an elevation of 7620 m. in the Central Himalaya near Tibet In Nepal, it is known as the Narayani joined by Indumati, Bhanumati and Bagmati It runs for about 425 kms. in India and finally joins the Ganga near Patna

The Arun river is one of the seven feeders of Sapt Koshi. In the high mountains, the Arun has several branches which are fed by the glaciers of the Gauri Shankar-Everest-Makalu-Kanchenjunga group of peaks. In the upper reaches, they all form deep gorges through their passages in the Himalayas. It originates near the Shisha Panga peak (8013 m.) in Tibet. From here it flows east and then from northeast of the Everest-Makalu massif it swings southwards. Besides, these Himalayan rivers, the Ganges also receives water from the Chambal, the Betwa and the Son.

The Ganga is a braided river with numerous channels with sand bars The Yamuna on the other hand flows between steep banks which are subjected to intensive gully erosion giving the landscape alongwith the Chambal a typical **badland** type of topography. The Ganga is known as the *Megbana* in Lower Bengal.

The Brahmaputra System

The Brahmaputra known as the Tsangpo in Tibet rises from the snout of the Chemayungdung glacier near Tacehong Khabab Chhorten about 100 kms. southeast of Mansarovar It flows eastwards for about 1700 kms. through southern Tibet. In this reach, it is joined by a number of tributaries. Near Lhotse Dzong, it opens out into a wide navigable channel for about 640 kms Thereafter the river breaks through a succession of rapids It enters in a great loop southwest through Arunachal Pradesh in India, first as the Siang and then as the Dihang. Emerging into the Assam valley, it is joined by two tributaries-the Dihang and the Lohit. From here onwards, the river is known as the Brahmaputra. After flowing for 720 kms. in the Assam valley, it enters Bangladesh and joins Ganga at Goalundo Their combined flow meets the Meghana about 105 kms. from Goalundo From here southwards, the river forms a broad estuary before flowing into the Bay of Bengal. The total length of the Brahmaputra is 2900 kms. A large number of streams descend to the Brahmaputra from the Himalayan ranges to the north. Among them are the Subansiri, the Kameng, the Manas, the Mora, the Gangadhar, the Raidak, the Dharla and the Teesta. The streams joining the Brahmaputra from the south are the Burhi Dihing, the Dhansiri and the Kalang. The Brahmaputra has a braided channel for most of its course and the streams shift constantly. The river causes enormous quantity of water and silt to be laid down on its bed which is the cause of disastrous floods year after year. No wonder, the river is called the "sorrow" of the region

Table 3.2 The Brahmaputra river system

RIVER	SOURCE	LENGTH (in kms.)	DRAINAGE AREA (in sq. kms.)	IMPORTANT TRIBUTARIES
FROM NORTH				
The Subansiri (known as the Lohit in the lower reaches)	In Tibet	442	32,640	The Kamla
The Jia Bhorelli (also known as the Kameng)	In Tibet	264	11,843	The Bichom, the Khari, Dikari, the Sonai, the Tongsa, the Kur

The Manas	In Bhutan	376	37,500	The Tonsa, the Kur
FROM SOUTH				
The Buri Dihang		362	8,473	The Namphunk, the Namchik, the Manaton, the Tirap
The Dhansiri	In Nagaland	354	12,250	The Dihing, the Diphu, the Nambar, the Kalyan
The Koppili	Mikir North, Cachar hills	256	15.800	The Jamuna, the Borpani, the Umum
JOINING	IN BANGLADESH			
The Teesta	In Sikkim	309	12,540	The Rajani, the great Ranjit, the Lish, the Gish, the Ghel.
The Jaldhaka	In Sikkim	186	3,958	The Murk, the Dihana,
The Torsa	In Chumbi valley of Tibet	358	4,883	The Holong, the Kalgani.
The Barak	Manipur hills	902	25,900	The Jiri, the Chiri, the Horong, the Katakhel, the Longai
The Soorma, the Rajma				

Himalayan and Peninsular Drainage

1. The Himalayan rivers are perennial; they are dependent on snow melt as well as on rainfall while the Peninsular rivers are not perennial; they are seasonal as their flow is mainly dependent on rainfall. Even the rivers which overflow their banks during winter dry up during summer.

2. Many Himalayan rivers have cut deep valleys during the long periods of erosional activity. The Himalayan rivers display youthful topography. On the other hand the Peninsular rivers flow through shallow valleys which are more or less graded. Peninsular rivers are in their mature or old stage. [broad valleys]

3. In the lower reaches on the plain, the rivers display a strong meandering tendency and often shift their course while the hard rock bed and the predominantly non alluvial character of the plateau surface hardly allow any meandering. Many of the Peninsular rivers have straight, linear and a well defined courses.

The Peninsular Drainage

The Peninsular drainage has existed for a much longer period of time than the Himalayan rivers. This is seen in the broad largely graded and shallow valleys of the Peninsular rivers which is indicative of the fact that they have acquired maturity. The beds have a very subdued gradient except for a limited tract of the rivers where faulting has allowed steepening of the gradient. (include this in str. and relief of Pen. India.)

The Western Ghats, very close to the west coast is the chief water divide but most Peninsular rivers flow towards the east. The Narmada and the Tapti are the only notable exceptions which flow in a rift valley before emptying them in the Arabian Sea. The Western Ghat was the original water divide but the subsidence of the western flank of the Peninsula has led to submergence and consequently disturbed the generally symmetrical plan of the rivers on either side. During the collision of the Indian plate, a second major distortion was introduced in that the Peninsular block was subjected to subsidence and consequent trough faulting through which now flows the Narmada and the Tapti. Because the Peninsular rivers originally filled cracks with their detritus there is a general lack of alluvial and deltaic deposits.

The Peninsular rivers fall into two major categories - (a) the coastal rivers and (b) the inland rivers. The coastal rivers draining into the Arabian sea are comparatively small streams but are numerous, about 600 in all. Only the Narmada and the Tapti are the major west flowing streams. Major rivers of the Peninsula such as the Mahanadi, Godavari, Krishna, Kaveri flow eastward and drain into the Bay of Bengal building huge deltas. Some rivers are associated with inland drainage such as the Mahi and the Sabarmati while some are just tributary to the Ganges and the Yamuna such as the Chambal and the Betwa.

The Narmada rises at an elevation of 900 m. in the Amarkantak plateau in Madhya Pradesh. It flows westwards descending over the basaltic cliff and then slopes down to Jabalpur where it cascades 15 m. into a gorge to form the Dhuandhar or the Marble Falls. Downstream of Jabalpur it flows along the northern edge of an asymmetrical valley through alluvial basins alternating with gorges enclosed between the Vindhyan and the Satpura ranges. Further downstream of Tawa confluence, it forms the Mandhata gorge. At Murakata, it again form a gorge rising over 1000 m. in the Akhrani Hills of the Satpura Range It finally emerges from the hills near Gardeshwar and meanders through an alluvial plain past Broach to open into the Gulf of Khambhat. The Narmada flows for a total distance of 1312 kms. draining an area of 78,796 sq. kms. The drainage area mostly lies in Madhya Pradesh.

During much of its journey the Narmada flows through a narrow rift valley confined within precipitous hills which do not favour development of tributaries However, on the left, a few small channels drain into it from the Satpura range, for example, the Tawa which rises from the Betul plateau and joins the Narmada near Hoshangabad.

The Tapti rises near Multai in Betul district at an elevation of 792 m. Running for 724 kms. westwards parallel to the Narmada in the rift valley, it drains an area of 65,145 sq. kms in Madhya Pradesh, Maharashtra and Gujarat. The important tributaries are the Purna, Betul, Lavda, Vaghur, Patki, Gerna, Ganjal and the Aner. The Tapti finally drains into the Arabian Sea beyond Surat in a narrow estuary.

Neither the Narmada nor the Tapti form deltas. This is because they flow through hard rocks for practically all along their courses and therefore were not able to form distributaries ~~Bcl~~ thus, they form estuarie

Besides these two rivers, numerous small streams spring from the Sahyadri Ranges and descend swiftly down into the narrow plains of the west coast and pour into the

Arabian Sea forming indentations and creeks. This is in contrast to the east coast which is almost unbroken and straight. Many west flowing streams have created impressive waterfalls such as Bedti Falls (137 m.), Jog Falls (253 m) on the Sharavati, Chalabudi Falls (56m.) and several others ranging from 20m. to 30m. on the Anaimalai-Palni -Elamalai hill chain.

The Sabarmati and the Mahi drain the northwestern flank of the plateau. The Sabarmati after rising from the Aravalli hills flows for about 300 kms. south - southwards draining about 21,674 sq kms of area. The Mahi which rises in the Vindhyan uplands flows 533 kms southwestwards before draining into the Gulf of Cambay. The Luni river forms an area of interior drainage. The source is in Annasagar in Ajmer district and drains an area of about 37,256 sq. kms.

The Luni (Sanskrit: *'Lavan'*-salt) is the only stream that drains through the arid Thar Desert of Marusthali. It rises from the Aravalli range, flows from Rajasthan Bagar to the Rann of Kachch for 450 kms. It ends in a small delta which was formed when the Luni carried a huge quantity of sediment. It is now an **ephermal** stream which gets lost at many places. Sukri is its most important tributary

There are three major systems of east flowing rivers- the Mahanadi, Godavari and the Krishna.

The Mahanadi rises near Pharsiya village in Raipur. It has a length of 890 kms. and its 141,600 sq. kms of drainage basin is shared by Maharashtra, Madhya Pradesh and Orissa The Mahanadi is joined by the Sheonath and Hardeo on the left bank and the Jonk and the Tel on the right, before draining into the Bay of Bengal where it forms a delta The delta, although slightly arcuate, is much straighter along its seaward front than the highly dissected Ganga delta.

The Godawari known as *the Vriddha Ganga* or the *Dakshin Ganga* rises from Trimbak in Nasik at an elevation of 600 m. The Godavari flows through gneisses and Gondwana sediments for 1450 kms. draining an area of 3,12,812 sq. kms. It cuts a transverse gorge 60 kms. long and 200 m. wide through the Eastern Ghats about 100 kms. from its mouth. The delta of the Godavari is of **lobate type** with a round bulge and many distributaries. It projects a front of about 110 kms. The northern part is made of low lying marshes extending into a 15 kms. long spit forming the Kakinada Bay.

W. Ghats

The Krishna rises from a spring near Mahabaleshwar. It is joined by the Koyna Ghatprabha, Malprabha, Bhima, Tungabhadra, Musi and the Maneru along its stretch of 1400 kms. South of Bijapur, the river enters the Dharwarian gneissic terrain and creates a waterfall before entering the Jaldhurg gorge. Further downstream, it has created a gorge through the Srisailam plateau of Cuddapah group and continues to flow through it before finally emerging in the coastal plain south of Jaggyapeta The delta formed by the Krishna is of **digitate type** (much less complex and smaller) and it has merged with the delta of the Godavari.

The Kaveri rises from Brahmagiri on the Coorg plateau on the edge of the Sahyadri Range. The river flows across the strike of the country-rock It is supposed to be an ancient river whose meandering course has been superimposed on a topography which has become youthful as a result of recent earth movements. The river creates a waterfall at Sivsamudram (101 m.) before entering into a 200 m. deep gorge. At places it cuts through the Eastern Ghats and finally drains into the Bay of Bengal forming a delta. about 8000 sq kms The delta has ...eated uplift and erosion

The other Peninsular rivers include the Subarnarekha rising from the Ranchi plateau, Koel and the Sankh also from the Ranchi plateau which continue downstream as the Brahmani river. The Damodar divides the Chhotanagpur plateau into two parts- the Hazaribagh and Ranchi plateau.

The Vamsadhara and the Nagwali rise from the Eastern Ghats, the Penner rises from the Nandi Durg and flows between the Kaveri and the Krishna.

The Palar and the Ponnaiyar are short streams confined between the coastal tracts of the Krishna and the Kaveri.

The Tambraparni which rises from Agastyamalai Hills form many beautiful waterfalls.

South of the Kaveri delta is the Vaigai which flows through dry channels and have a tendency to get intermittently lost in the ground and reappear again.

Table 3.3 Peninsular rivers: their sources, tributaries, and drainage

RIVER	SOURCE	LENGTH (in kms.)	AREA in sq.kms.	
WEST	FLOWING RIVERS			
Narmada	Amarkantak plateau in Madhya Pradesh	1,312	98,796	Burner, Baiyar, Sher, Dudhi, Shakkar, Tawa, Hiran, Tendoni, Barna, Kolar, Anjal, Machak, Kundi, Gol, Karyan.
Tapi	Near Multan in Betul district	724	64,145	Purna, Betul, Levda, Vaghur, Patki, Ganjal, Dhatranj, Bohad, Bori, Anbhora, Khursi, Kapra, Sipra, Panjhara, Garja, Khokri, Utaoli, Bokar, Subi, Mor, Mautri, Guli, Aner, Arunavati, Gomal, Harki, Valer, etc.
Luni	Annasagar in Ajmer district	482	37,250	
Sabarmati	Aravalli hills	300	21,674	Wakal, Jawai, Mitri, Sei, Harnav, Hathmathi, Watrak, Meshwa.
EAST	FLOWING RIVERS			
MAHA-NADI	SYSTEM			
Mahanadi	Near Pharsia village in Rajpur district	860	1,41,600	Sheonath, Hadse, Mand, Ib (left bank), Jonk, Ong, Tel (right bank).
Brahmani	Near Nagri village of Ranchi District	800	39,033	Kura, Sankhed, Tikra.
Baitami		333	19,500	
Subar-narekha	Bihar	395	19,300	Kanchi, Karfari.

GODAVARI	SYSTEM			
Godavari	Trimbak in Nasik	1465	312,812	All the following rivers.
Parvara	Western Ghats	200	6,537	Mula.
Purna	Ajanta hills	373	15,579	
Manjra	Balaghat	724	30,844	Tima, Lanaya.
Painganga	Buldhana Range	676	23,895	Pus, Arna, Aran.
Wainganga	Seoni	609	61,093	Pench, Bagh, Andhari.
Wardha	Betul district	483	24,087	Wunna, Bembla, Painganga.
Pranhita		133 after confluenc	1,09,077	Wainganga, Wardha.
Indravati	Kalahandi	531	41,665	Narangi, Kotri, Bandia, Nandira.
Maner			13,106	Haldi.
Sabari	Sindaram hills	418	2,40,427	Sileru
KRISHNA	SYSTEM			
Krishna	At an altitude of 1,360, north of Mahabaleshwar	1,400	2,58,948	All the following rivers.
Koyna				
Ghatprabha	Western Ghats	283	8,829	Hiranyakshi, Markandeyu.
Malprabha	Western Ghats	306	11,549	
Bhima	Western Ghats	861	76,614	Mula, Mutha, Ghod, Nora.

Tungbhadra		531	71,417	Varada, Hagari.
Musi	Madek District	240	11,212	Aleru.
Muneru		235	10,409	
KAVERI	SYSTEM			
Kaveri	Brahmaputra hills	800	87,900	All the following rivers.
Harangi	Pushpagiri hills, Coorg district	35	540	
Hemvati	Western Ghats in Mudgil Taluk	165	5,200	Yagachi Algur.
Kabini	Wynad Taluk	210	6,693	
Suyar-nayathi	Nasurum Ghat	64	1,689	
Bhavani	Silent Valley Forest	216	7,144	Siruvani, Kundah, Coonoor, Moyar.

Source M S Krishnan, Mamoria

The Drainage Pattern in India

India is so vast with so much variations in physical background that all sorts of drainage pattern and texture is found. The drainage pattern refers to the pattern that many streams collectively form.

Dendritic Pattern

The Dendritic pattern with its tree like disposition has its best example in the form of the Indo-Gangetic plain. Here the various tributaries have joined the Ganges at fairly acute angles implying that there was very little structural control. Many streams of Peninsular region also have dendritic pattern. Much of this region represent very old erosion surfaces which were peneplained. In a peneplain there is negligible effect of

structure on the pattern. However, within the general pattern of the streams of the Peninsular upland there are evidences of some structural control.

Parallel pattern

The Parallel patterns are usually found where there are pronounced slope or structural controls which lead to regular spacing of parallel or near parallel streams Such a pattern is found on the western coastal strip and in many parts of the eastern coastal lowlands. On the west the relatively young and steep Western Ghats have given rise to a number of streams emerging from their crest flowing rapidly down their slopes and joining the sea independently. These streams which originated with the formation of the Western Ghats have not been very effective as captor stream. Therefore, most of the consequent streams follow the general westerly slope of the relatively new surface on the Ghats and the coastal lowlands.

However, in many cases, the gradient is gentle owing to recession of Ghats as in the case of the Nilgiri and Kerala hills where a number of tributaries have been integrated into dendritic pattern in the upper section of the streams However, minor structural control is evident throughout the Western Coastal Plain where the rocky eminences have diverted the streams from their straight courses giving them considerable sinuosity. In the section of Ratnagiri Coastal Plain of uplifted Tertiaries the parallel pattern is remarkable. The emergent Eastern Coastal Plain except in the deltaic sector shows striking parallel pattern.

Radial pattern

Radial pattern of drainage is quite obvious in Kathiawar where there are no longitudinal structural trends facilitating rectilinear pattern. This pattern is surrounded practically on all sides by the sea and there is a highland in the centre causing the streams to radiate from this central highland. Another example of radial pattern is the Indravati basin

Pinnate pattern

Pinnate pattern is a feather like drainage pattern containing a large number of closely spaced tributaries. It is found in the Narmada and the Tapti valleys.

Trellis pattern

It consists of a series of sub parallel streams along the strike of the rocks. The larger transverse streams flow along the dip in their effort to cut across and thus arrange themselves in rectangular bands This pattern reflects striking control of structure. Except for the major transverse streams like the Arun, Kosi, Karnali, Gandak and the Brahmaputra which are either consequent upon the general southerly slope of the Himalayas or antecedent most of the Himalayan rivers show marked structural control. The main consequent river runs across the Himalayan wall in a north-south direction. Then there are the major tributaries running in an east-west direction. The primary tributaries initially seated themselves on original synclines of the Himalayan folding and have subsequently shifted to the adjoining anticlinal position by inversion of relief. At the same time the primary tributaries persist to form the strike valleys Then there is a third set of streams parallel to the north-south transverse master stream. These form the secondary tributaries parallel to dips and transverse streams. The fourth set of streams is parallel to the same direction but is generally shorter than those from the north It may be called obsequent in the sense that they are opposed to the flow of the transverse master consequent rivers

The trellis and the rectangular pattern is the characteristic feature of many parts of Peninsula where the rivers show marked structural control.

The **texture of drainage** refers to the relative spacing of drainage lines implying the **drainage density** and **stream frequency**. Drainage density means total length of streams in an area divided by the streams while stream frequency means the number of streams divided by the area of the basin.

The factors controlling the drainage texture are climate, permeability of the underlying rock and bedrock relief.

Climate and precipitation has a direct control over drainage texture. An area of heavy rainfall is marked by numerous streams. Vegetation also affects the drainage texture. A semi-arid region with poor vegetation has finer drainage texture than a region with dense vegetation. Permeability of the underlying surface has a direct effect on texture. The streams seep through permeable strata. Consequently, there are a few drainage lines, while they are numerous on an impermeable strata. In areas having irregular relief walls have more drainage lines than monotonous surface. A mature stage

of cycle of erosion will have finer texture than the youth stage. Badland type of topography is one set of condition leading to finer drainage texture. In glaciated areas, on the sand and gravel outwash plains and valley terrains the high permeability gives a coarse drainage texture.

Applying these concepts to India it is found that in the area of consolidated rocks of high relief on the Northwest Hills bare of vegetation results in a very fine texture of drainage. On the contrary there are few drainage lines in the permeable soil region of the Indian desert and the sandy areas of the Punjab. The Himalayas and the Northeast hills have medium to fine texture. In the Bhabar region where the vegetation cover is dense the texture is coarse while in the Siwalik region the texture is much finer on account of consolidated nature of the soil. In the Indo-Gangetic alluvium, the texture is fine to medium depending on the amount of rainfall. Higher rainfall causes fine texture and vice versa. Thus, the texture is coarse in the Punjab and Uttar Pradesh whereas it is finer in Bihar, Assam and Bengal. In the Peninsular India the texture is medium to fine with no marked variations in the permeability of the structure and soil. The areas of higher relief, however, have a finer texture than those of low relief.

Sir

Drainage Regionalisation of India

India can be divided into the following drainage regions based on the source and direction of rivers. Thus, each drainage region confirms to the river basin of India. The main river basins and important rivers are:

CHAMBAL

1. Ganges	Yamuna, Ramganga, Gandak, Ghaghara, Kosi, Gomti, Son, Damodar
2. Brahmaputra	Subansiri, Kameng, Dihang, Jaldhaka, Teesta, Barak, Dhansiri, Soorma
3. Indus	Shyok, Nubra, Skardu, Zanskar, Gilgit, Ravi, Jhelum, Chenab, Beas.
4 Sabarmati	Wakal, Jawai, Mitri, Meshwa, Sei, Hamav, Hathmathi, Watrak.
5. Mahi	

6 Narmada	Dudhi, Shakkar, Tawa, Machak, Kundi, Goi, Burner, Baiyar, Sher, Hiran, Tendoni, Barna, Kolar, Anjal, Karyan
7 Tapi	Purna, Betul, Levda, Vaghur, Patki, Ganjal, Dhatranj, Bohad, Bori, Anbhora, Khursi, Kapra, Sipra, Panjhara, Garja, Khokri, Utaoli, Bokar, Subi, Mor, Mautri, Guli, Aner, Arunavati, Gomal, Harki, Valer, etc Arunawati
8 Mahanadi	Ib, Ong, Tel, Sheonath, Mand, Ib, Jonk, Hadse
9 Godavari	Pranhita, Manjra, Wardha, Wainganga, Indravati, Sabari, Pravara, Purna, Maner
10 Krishna	Ghatprabha, Malprabha, Bhima, Tungbhadra, Musi, Koyna.
11 Kaveri	Hemvati, Harangi, Shimsha, Lokpavani, Bhavani, Suyarnayathi, Kabini

Important Words

Antecedent Rivers	Badlands	Ephermal Streams
Lobate type	Digitate Delta	Dendritic Pattern
Parallel Pattern	Radial Pattern	Pinnate Pattern
Trellis Pattern	Drainage Texture	Drainage Density
Stream Frequency		

4

CLIMATE

Introduction

Latitudinally, India lies half in the tropics and half in the sub tropics. But even though half of the region lies outside the tropics, the climate of India is basically tropical in character. It is essentially due to two factors - the Himalayan mountain complex in the north which shields the whole of India from the intensely cold Central Asian winds, and the thermal shifting of the equator which brings the whole of India under tropical climatic conditions; when the Himalayas are insulating the Indian subcontinent. Consequently, the essential characteristics of climate is always tropical in character This tropical climate is marked by distinct winter and summer seasons. The rain comes in summer in one part of the country and in winter in another part. This seasonal pattern is the result of seasonal variation in the temperature and pressure pattern and its resultant effect on the direction of wind, which brings about a marked reversal in the wind direction. This seasonal reversal has been described in one word **"Monsoon"**. The monsoon type of climate is thus characteristics of the whole of India.

The Monsoons

There are, however, wide regional variations within this monsoon region. For example, the climate of South India differs from the climate of North India. Not only does the climate of north and south India differ, there is wide difference even within South India, for example, between Kerala and Tamil Nadu. These differences are reflected in temperature, pressure, winds, moisture and precipitation conditions. Churu, Barmer may record a temperature of 48°C to 50°C in June while temperature hardly rises beyond 25°C in Srinagar on the same day. On a December night, the temperature may drop to -40°C at Kargil and Siachen while on the same night it is only 20°C to 22°C

in Chennai, Vishakhapatnam, Pondicherry. The differences are also quite striking in rainfall The annual rainfall in Jaisalmer hardly exceeds 12 cm. while Mawsynram may get 8 years of this equivalent rainfall on a single day.

The western coast from Kerala to northern tip of Maharashtra receives very heavy rainfall during July and August while the whole of Coromandal coast goes dry. During the same period the Orissan coast gets hit by rainfall almost every 4th or 5th day. The Brahmaputra valley gets flooded within the very first week of being hit by monsoon while during the same period there is no indication of any rain in Rajasthan desert.

The interior regions such as the Punjab, Haryana, northwest Uttar Pradesh and adjoining portion having continental location have extremes of temperature -very high temperatures in summer and very low temperature during winter while the regions affected by **oceanicity** such as Mumbai, the Konkan and the Malabar coast have hardly any range, annual or diurnal.

Apart from these, variations also exist in terms of onset and withdrawal of monsoon. Kerala, Malabar and the Konkan coast get rains during the first week of June while the advent of rains may be delayed by as much as last week of June in Delhi.

The differences in local climate is the result of many factors. These are broadly

1. Surface pressure distribution and winds.
2. Upper air circulation, particularly **Jet Stream** and the divergence and convergence associated with it.
3. Inflow of western disturbances **(depressions)** during winter and tropical depression during Southwest monsoon.
4. The surface configuration particularly the distribution of the mountain ranges.

The Southwest Monsoons

(1) They blow from the southwest direction.

(2) They first strike the southern tip of India. The onset is a gradual process but they arrive in the form of bursting.

(3) The rainfall brought by the monsoon decreases away from the sea.

(4) Over 10 per cent of country's rainfall is received by the southwest monsoon.

(5) The monsoon do not give rise to a simple pattern of weather all over India, there are dry areas, Semi-arid and humid areas.

(6) The monsoon are pulsating in nature.

(7) The monsoon vary from year to year.

(8) Within the monsoon region there is high reliability and variability of rainfall.

(9) The duration of monsoon is from 100-120 days.

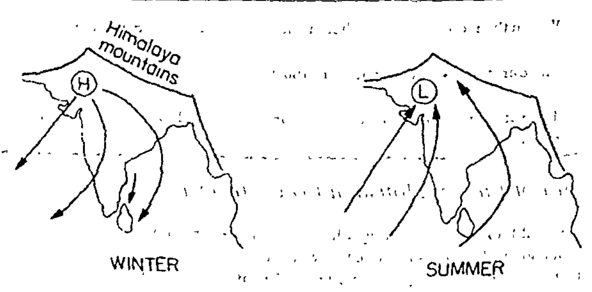
(10) The withdrawal of monsoon is a much more gradual phenomena than its arrival.

Origin of Indian Monsoon (The earlier view)

It is well known fact that from a high pressure region the wind has a tendency to flow out and in a low pressure zone the wind has a tendency to flow in. In other words, the high pressure is related with **centrifugal (anticyclonic) flow** whereas the low pressure is related with **centripetal flow**. Thus, the weather pattern is influenced by the formation of these high and low pressure cells. In winter, the region lying to the north of the Himalayas becomes a centre of high pressure. High pressure is produced by the cooling of the surface. The Winter circulation at the surface in India is dominated by anticyclonic conditions, both to the north and to the south of the Himalayan-Tibetan mass. This forms an effective barrier to communication between sectors of the surface circulation. The Indian Subcontinent, is thus, isolated from the rest of Asia. Winds blow

outwards from the land, over which air is subsiding (because of the high pressure), Over India, this air is cool and dry and flows through the entire stretch of the Gangetic plain, crossing the Bay of Bengal, and when it had picked up enough moisture rises along the Eastern Ghats due to orographic effect and pours it down in the eastern coastal region This is the winter rainfall of South India which is **orographic** in nature and often brings flood in the parts of Tamil Nadu. There is a gradual transition from this situation from winter to summer. With the thermal shifting of the equator, the whole scene changes. The Sun is shining vertically over the Tropic of Cancer. The high pressure centre vanishes and a low pressure centre is created in the northwestern part of India. This invites inflow of winds from all directions. The trade winds while reaching to fill this low pressure zone crosses the entire length and breadth of the Arabian Sea and the Indian Ocean. This makes these wind moisture laden and thus they cause heavy downpour *when they strike the Western Ghats and the Himalayan ranges. This is by* definition, the southwest monsoon (Fig. 4.1). The **'traditional'** view that wind reversal is due merely to difference in surface heating is typical of the simple explanation given before extensive investigations were made of conditions aloft.

Fig.4.1. The Traditional view on the origin of Indian monsoons



Origin and mechanism of monsoon

(Recent explanations)

However, the pattern of pressure and temperature distribution is not as simple as made out by the above analysis. When this analysis was made not much information

was available regarding causes of pressure difference, spatio-temporal variations, the relationship of monsoons with the flood and drought conditions, the transition of the seasons, the generation of tropical depressions and their track, etc. Broadly, none of the characteristics of the monsoons and the Indian climatic conditions were known nor were they explained. With an increased knowledge about the upper air circulation, the Indian weather conditions, in general, and monsoons, in particular, can be much better explained.

Winters

Above 3000m, the circulation is quite different. A strong easterly flow, including the Jet Stream flow across the Asian continent at latitudes north of Himalayas roughly parallel to the Tibetan highlands, which act as barrier to this movement The effect of the Tibetan plateau is to bifurcate the Jet Stream into two parts (they again unite off the east coast of China) (Fig. 4.2). This disruptive effect is limited to altitudes below about 4000m. In fact, the northern jet is highly mobile and may be located far from the

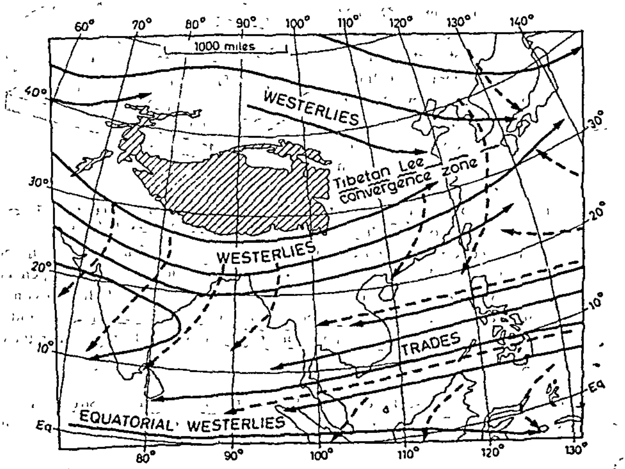


Fig.4.2. The jet stream circulation around the Tibetan plateau

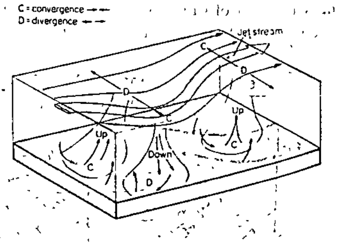
Tibetan plateau. The southern branch is located over northern India corresponding to a very strong thermal gradient which prevails from November to April. The mean position of the southern branch of Jet Stream is about 25°N lat, in February at 200 to 300 mb and has an average speed of more than 40 m s^{-1} (90 mph) at 200 mb, compared with about 20-25 m s^{-1} (45-55 mph) for the northern one Where two unite over north China and south Japan the average velocity exceeds 66 m s^{-1} (148 mph).

The upper air flow has two effects i.e. intensifies (H) (H) & (L) both are now present.

(i) It intensifies surface anticyclone, and

(ii) It brings strings of surface cyclonic disturbances. i.e. (L)

Air subsiding beneath the upper westerly current gives rise to dry outblowing northerly winds from the subtropical anticyclone over Northwestern India (Fig 4 3) The surface wind direction is north-westerly over most of northern India and easterly over Peninsular India The general pattern of weather is warm and dry, and some rain in Peninsular India. The upper jet at the same time steers the western depressions over northern India. The lows which are not usually appear to penetrate across the East from the Mediterranean and are important sources of rainfall for northern and Northwest India especially as it falls when evaporation is at its minimum. The general pattern of dry weather is thus interrupted by some cloud and rain, (which becomes snow on the Himalayan slopes) and even by cold spells as cP air spills into Indus lowlands In the extreme northwest, these winter rains are generally greater than those received in summer.



These disturbances usually occur to the east of the westerly Jet Stream. These climatic disturbances are generally preceded by warm weather or sudden rise in

temperatures. After the rains which are light and spread over a couple of days they are followed by clear skies and drop in temperature. Occasionally, in their trail they bring in severe **cold waves**. The cold wave is generally defined by fall in temperature by 5°C or more from the normal.

As the air flow passes over the Bay of Bengal it picks up moisture and becomes involved in weak tropical disturbances which bring rain to south eastern India and the east coast of Sri Lanka.

Thus although most of India is dominated by winter drought it may be interrupted by rains in the extreme north and south, and even elsewhere where the northern cyclones draw in mT air from Indian ocean. Temperature remains high because of protecting effect of the Himalayas and the Tibetan plateau. Thus Calcutta is 7°C warmer in February than Hongkong while both lie on the same latitude (22 1/2° N).

Spring

The spring is the transition season where the pattern of the the upper air flow changes. In March, the westerlies begin their seasonal migration northward. During March, the northerly jet strengthens and begins to extend across Central China and Japan, while the southern branch remains positioned south of Tibet although its strength and intensity diminishes. India is still dominated in spring by a subsiding and outward blowing anticyclonic circulation and the clear skies allow maximum and increasing insolation. High temperature, a heavy heat haze and drought are the characteristic feature of the weather in the central areas. Greater solar radiation heating intensifies squally disturbances. Some precipitation occurs in the north with "Westerly disturbances" particularly towards the Ganges delta where the low level inflow of warm humid air is overrun by potentially cold air triggering squall lines known as '*nor westers*' (because they appear to come from northwesterly direction).

The [illegible]s convection and thunderstorm formation due to explosive [illegible] the afternoon (such convection was prevented when Jet Stream was strongly developed). In the northwest, such conditions give rise to "*andhis*", - dust storms, forming in the absence of atmospheric moisture.

Summer

As the summer sets in and the sun shifts northward many changes take place

(a) Nearer the surface, the low pressure belt has formed consequent upon intense solar heating. This in fact is the **Inter Tropical Convergence Zone (ITCZ).**

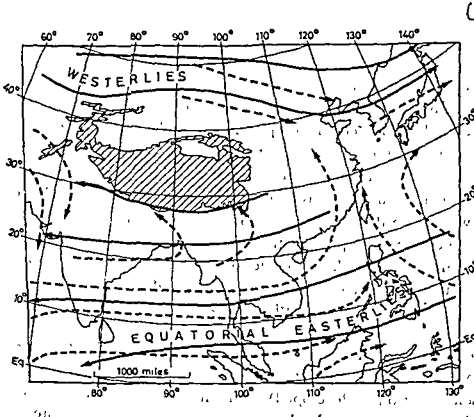
(b) The westerly jet moves north of the Himalaya- Tibetan mountains, (Fig.4.4) and

(c) the easterly winds are established over India., } (1) What are these doing ?

All of these changes are interrelated.

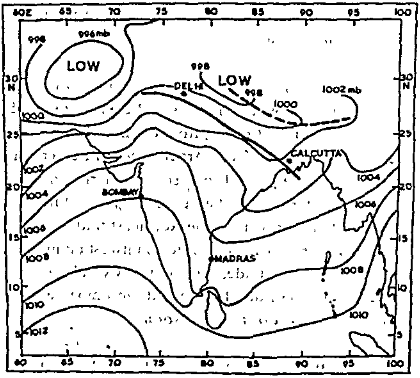
(2) Eqt^r. easterlies are different to Easterly (upper troposph Jet stream

Fig.4.4. The location of westerly jet stream north of the Himalayas



The summer months are a period of rising temperature and falling air pressure in the northern half of the country.

Fig.4.5: The location of monsoonal low pressure trough in India.



The equatorial low pressure trough has already started moving north. Towards the end of May an elongated low pressure area is developed. It is called the **"Monsoon Low Pressure Trough."** It extends from the Thar desert in the northwest to Patna and east Chhotanagpur plateau in the east-southeast (Fig 4 5). In the heart of the low pressure trough in the northwest, the dry and hot winds blow in the afternoon and sometimes they even continue till midnight. These hot and dry day winds are locally called loo. Dust storms are common in the evening in May in the Punjab, Haryana, eastern Rajasthan and UP. These are the result of convection and explosive cumulonimbus growth because of weakening of the Jet Stream. These dust storms or *andhis* as they are called although temporary, bring welcome respite from the oppressing heat since they bring with them pleasant cool breeze.

Occasionally, some moisture laden winds are attracted towards the periphery of the trough. A sudden contact between dry and moist air masses gives rise to local storms of great intensity. These local storms are associated with violent winds, torrential rains and hail storms locally known as **Norwesters.** In the northeastern region they are called '*Kalbaisakhi*' (calamity of the month of *Baisakh*). Towards the beginning of **pre-monsoon** showers are a common phenomena in Kerala and coastal areas of Karnataka. Locally they are known as '*mango showers*'. Incursions of the **pre-monsoon**

showers and early start of the monsoon further north is checked by a belt of relatively high air pressure zone lying over the Deccan plateau. In the coming months, there is further intensification of the monsoon trough assisted by the northward movement of the jet further towards Tibet. The presence of the jet impeded convection throughout the winter and spring.

The

are of oceanic origin Coming from the Indian Ocean they cross the equator and enter the Bay of Bengal and the Arabian sea. After crossing the equator they follow a Southwesterly direction. These southwesterly winds while travelling on the warm Arabian sea water have picked up enough moisture and is by definition known as the **southwest Monsoon** Thus the Northeast trades of winter originating on the land are replaced by diametrically opposite southwest monsoon laden with moisture (however, the monsoon like the trades are not steady winds rather they are pulsating). The sudden approach of the moisture laden winds accompanied by violent thunder and lighting is known as the ***burst of the monsoon***.

The southwest monsoon causes heavy downpour on the Western Ghats where the winds strike the mountains almost at right angles. Another area of heavy precipitation is in NE region where the Himalayas lie athwart the monsoon. North of it the rainfall goes on decreasing all along the Himalayas.

The Southwest monsoon thus coming from the Arabian Sea known as the **Arabian Sea branch** and the Bay of Bengal known as the **Bay of Bengal branch** (Fig.4 6) and is responsible for much of the rainfall over India

These low level changes are related to the establishment of a high level easterly jet stream over southern Asia at about 15°N (Fig .7). The northwestward

Fig.4.6. The two branches of the monsoon

Fig. 4.7. The easterly jet stream in relation to low level circulation

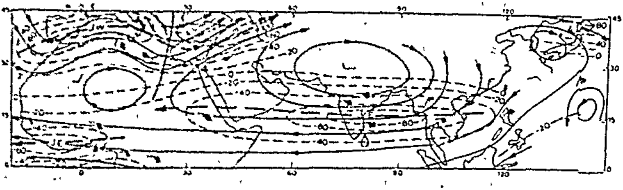
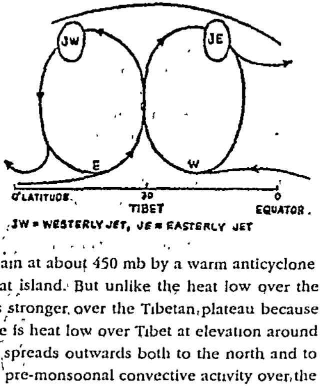


Fig4.8. The origin of easterly jet steam due to heating of the Tibetan highlands



movement of the monsoon is apparently related to the extension over India of the upper tropospheric easterlies.

The easterly Jet Stream owes its origin to the summer heating of the Himalayan and Tibetan highlands (Fig 4.8) The plateau surface is strongly heated in spring and early summer (net radiation is about 180 Wm^{-2} in May) and nearly all of this is transferred via sensible heat to the atmosphere. This results in the formation of a shallow heat low on the plateau overlain at about 450 mb by a warm anticyclone The plateau thus acts like an elevated heat island. But unlike the heat low over the Indian subcontinent thermal convection is stronger over the Tibetan plateau because of its higher elevation. Thus although there is heat low over Tibet at elevation around 500 mb (6kms.), the ascending air rapidly spreads outwards both to the north and to the south of the plateau. At the same time, pre-monsoonal convective activity over the south eastern rim of the plateau provides a further heat source by latent heat release for the upper anticyclone. The equatorward branch of the upper outflow from this anticyclone gains easterly angular momentum and the poleward branch westerly angular momentum. There are thus two jet streams, a westerly jet to the north of the anticyclone and an easterly jet to the south of it (Fig 4.8). The SW monsoon beneath the easterly Jet Stream flowing in reverse direction in the lower troposphere compensate for the mass. It is basically a return flow in the lower levels of the **meridional circulation system**. It is convergent and picks up enough moisture from warm sea

some depressions do not recurve but continue to move westwards and generate heavy rainfall over western India. Sometimes they become the reason for floods in Gujarat and Rajasthan.

they are much mild than tropic cyclones

The track of the monsoon depressions is along the axis of the monsoon trough of low pressure (Fig 4.10). As the axis of the monsoon trough oscillates the track of these depression also vary. When this axis lies in the plains, the plains receive fair amount of rainfall. On the contrary when the axis moves north and lies close to the Himalayan foothills the rains abruptly cease over the plains of northern India but increase equally rapidly in intensity over the foothills of northeast India bringing devastating floods. When the equatorial trough is farthest north there is marked tendency for less rainfall in southern India although the region lying in the lee of the Sahyadris derive much of their rainfall. When the axis of the monsoon trough moves south and dips into the Bay of Bengal, conditions are favourable for depression formation. Since, the westwards passage of depression is accompanied by heavy rains therefore southward position of monsoon trough augurs well for Indo Gangetic Plain and Central India. Most of these westward propagating systems are either linked to westward propagating system from the (1) northwestern part of Thailand or they (2) were remnants of tropical cyclones ***"typhoons"*** or they (3) originated in Bay of Bengal itself.

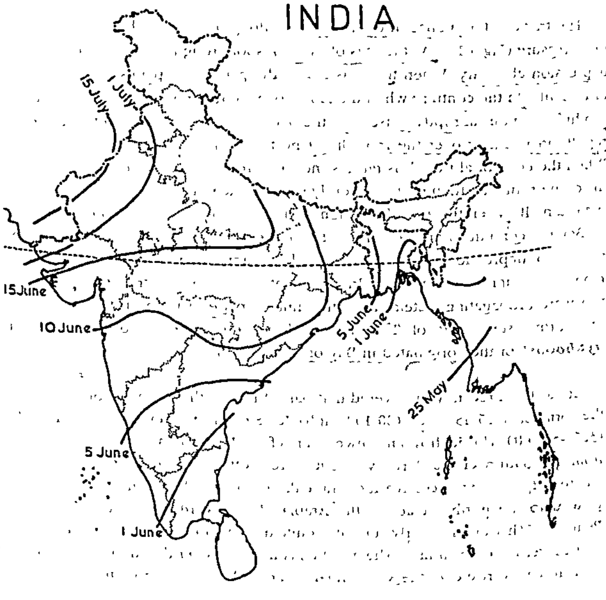
tropical cyclon form locally

It has been recently discovered that part of the southwest monsoon flow occurs in the form of a 15-45 $m\ s^{-1}$ (30-100 mph) Jet Stream at a level of only 1000-1500m (3250-5000 ft). This jet flows northwestwards from Madagascar and crosses the equator from the south over east Africa where its core is often marked by streaks of cloud and where it may bring excessive local rainfall. Then it is deflected by the East African plateau to the northeast across the Arabian Sea towards the west coast of Indian Peninsula. This southwesterly current is quite dry near the equator except for a shallow moist layer near the surface. The air obtains moisture over the Arabian Sea. The moist air is forced to rise over the Western Ghats and releases this moisture.

Very heavy rainfall over western India especially over the northern parts of Maharashtra, Saurashtra, Kachchh and Gujarat was associated with cyclonic vortices that were confined to the middle atmosphere and are not visible at the surface.

The dimension of these vortices is of the order of 300 kms. in the horizontal direction and about 3 kms. in vertical direction. These vortices remain quasi stationary for many days and is responsible for heavy rains on the northern sectors of the west coast of India. Although the precise cause of the formation of these vortices is not fully known

Fig. 4.11. The onset of southwest monsoons



it is thought to originate when the winds at lower level are stronger than the winds at upper level.

Apart from mid tropospheric cyclones, the spells of heavy rain are associated with off shore vortices. When the monsoon winds strikes the Western Ghats that runs for bout 1000 kms. in length, on many occasions they do not have enough energy to limb over the Western Ghats. Thus instead of crossing it they tend to be deflected

round the mountain. The return current then forms an off shore vortex. The diameter of these vortexes is about 100 kms. and their presence is often detected by a weak easterly wind at coastal locations. Notwithstanding their small dimension, they are capable of generating spells of very heavy rainfall lasting for two to three days.

The southwest monsoon, so-called because they follow a southwesterly direction, first strikes the extreme south of the Indian Peninsula, the Kerala coast when it is known as **'burst'**. Subsequently, its progress can be traced in the form of two branches - the Arabian Sea branch and the Bay of Bengal branches. The monsoon rainfall is characterised by declining trend with increasing distance from the sea.

Arabian Sea Branch and the Bay of Bengal Branch

The Arabian sea branch causes rainfall all along the west coast of Western Ghats - Maharashtra, Gujarat and parts of Madhya Pradesh. The monsoon winds which strike the Western Ghats shed off their moisture on the windward side of the Western Ghats. Trivandrum receive the first showers and thereafter the monsoons moves northwards. Ten days later it reaches Mumbai. Thus Mumbai receives 187.5 cm. of rain during the monsoon while Pune only 160 kms. away and in the lee of the Western Ghats receives only 50 cm. during the same period. Crossing the Western Ghats, they overrun the Deccan plateau and Madhya Pradesh causing fair amount of rainfall that goes on gradually decreasing. Thereafter, they enter the Ganga plains and mingle with the Bay of Bengal branch. Another part of Arabian Sea branch strikes the Saurashtra Peninsula and the Kachchh. It then passes over West Rajasthan and along the Aravallis causing only scanty rainfall. [Because the E. Jet stream subsides over E causing (H) ∵ no rai (anticyclonic circulation) as winds outwar

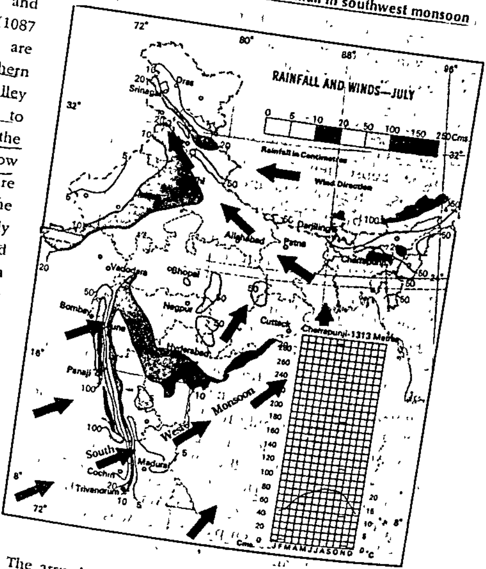
The Bay of Bengal branch moves northwards into the central Bay of Bengal and is directed towards the Burmese coast and parts of south-east Bangladesh. The Arakan

deflect a big chunk of this branch and enable it to enter

. oons, therefore, enter West Bengal and Bangladesh from south and southeast instead of southwesterly direction. Thereafter the branch splits into two by the effect of Himalayas and the thermal low in northwestern India. One branch moves westward along the Ganga plains reaching as far as the Punjab plains. The other branch moves towards the Brahmaputra valley in the north and northwest causing widespread rains in the Northeastern India. Its subbranch strikes the Garo and Khasi hills of Meghalaya. It is here that Mawsynram is located and its unique topographical location together with wind direction is responsible for receiving the heaviest rainfall

of the world (1141 cms/449 inches) Both Mawsynram and Cherrapunji (1087 cms/428 inches) are located at the northern end of a deep valley running from south to the north When the monsoon winds blow from the south, they are trapped within the valley and eventually strikes Cherrapunji and Mawsynram in a perpendicular direction at the end of the valley Thus the heaviest rainfall occur when the wind blows directly on the Khasi hills.

Fig. 4.12. The trend of declining rainfall in southwest monsoon



The other sub branch, on reaching the southern periphery of the Himalayan barrier, is deflected westwards towards the Gangetic plain The arrival of the monsoon over Calcutta (7th June) is slightly earlier than at Mumbai (10th June). The average rainfall over the North Indian plain generally remains between 100 and 200 cms during this period and shows a decreasing trend away from the sea. Calcutta receives 120 cms, Patna 105 cms and Allahabad 76 cms of rainfall (Fig 4.12)

After crossing Maharashtra and Madhya Pradesh the two branches merge into a single current and continue to move as one current towards West Uttar Pradesh, Punjab and eastern half of Rajasthan, where these regions have their first showers by the first week of July Thus these places can have rainfall from both the branches and it often

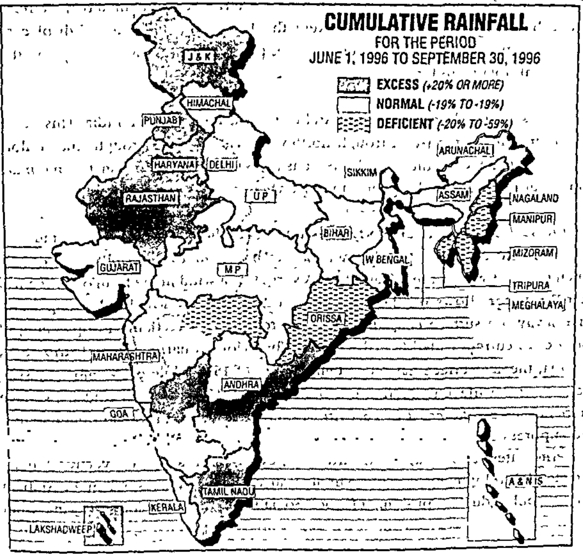
becomes difficult to discern whether Delhi (56 cms) had its first rainfall from Arabian Sea branch or the Bay of Bengal branch.

By mid July the monsoon extends into Kashmir and the remaining parts of the country but only as a feeble current because by this time it has shed most of its moisture

The monsoon current does not give rise to a simple pattern of weather over India, despite the fact that much of the country receives 80 per cent or more of its annual precipitation during the monsoon season. There are considerable spells of fine sunny weather at many places and many areas are semi-arid particularly in the rain shadow areas of Western Ghats and some in the north west. In the northwest, a thin wedge of

Fig.4.13. Cumulative rainfall for the period June1—September 30, 1996

(Rij case)



monsoon air is overlain by subsiding continental air. The inversion prevents convection and consequently little or no rain falls in the arid northwest of the country.

The eastern coast of India particularly Tamil Nadu remains relatively dry during the southwest monsoon period. This is because the Tamil Nadu coast lies in the rainshadow area of the Arabian Sea branch and is parallel to the Bay of Bengal branch.

Spatio-temporal variations in Southwest Monsoons

The southwest monsoon is highly variable from year to year (Fig 4.13). These variations are essentially caused by

(a) The southward movement of the midlatitude Westerlies accompanied by Jet Streams during the summer season. This weakens the Tibetan anticyclone and displaces it north eastwards. This re-establishment of jet prevents convective activity and thus the rain fall totals are low.

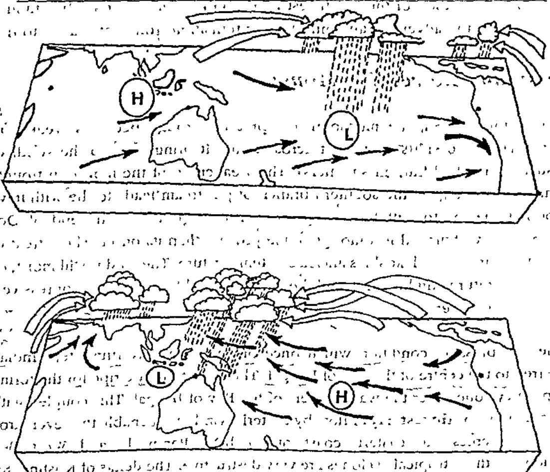
(b) The extension of subtropical high of Arabia eastward over Central India. This causes the shifting of the monsoon trough northward. The westerly troughs travel along the southern edge of the Himalayas causing widespread rains on the mountain slopes but little rain in the plains and elsewhere.

(c) The unusual cooling of surface temperatures over the Arabian Sea by as much as 3° to 4°C before the onset of the monsoons. This is due to the cool Somali current which pushes towards the Arabian Sea. A very strong wind in the form of jet (named after **Findlater**) flows off the coast of East Africa. These low level strong winds drive away the surface coastal waters towards the east resulting in upwelling of cool ocean current called Somali current. Thus along a narrow coastal strip along Somalia, the sea surface has a low temperature of 15°C while off Mumbai coast of India, the sea surface temperature is between 25-30°C. In view of cold sea surface temperatures off the coast of East Africa there is a marked inversion temperature and suppression of clouds as convective activity and evaporation is inhibited. But as warm waters appear again towards east, evaporation starts, convective activity and cloud development takes place under unusual circumstances. When the Arabian Sea is cooler, due to pushing of cool Somali current the winds blowing from

Southwest do not pick up as much moisture nor do they develop instability which is so necessary for rainfall generation.

(d) The *El Niño* effect, which is the periodic appearance of warm water off the Peruvian coast. This current replaces the cold Peru or Humboldt current and sea surface temperature may increase by 10°C. This has widespread effect on the world's climate. When the cold Peru or Humboldt current flows off the Peruvian coast, there is always a high pressure zone that is centred around in South Pacific. At the same time there is always a low pressure region centered around Indonesia and southeast Asia. The appearance of warm ocean current off the Peruvian coast means that there

Fig.4.14. The effect of El Nino on Indian monsoon (top), Normal condition (Below)



will be low pressure in the south Pacific Ocean and a simultaneously high pressure zone centered around Indonesia and southeast Asia (Fig 4.14). Applying the simple principal that wind always blows from high pressure to low pressure, it can be

shown that when there is normally cold current flowing (the Peru or Humboldt current), there is a high pressure zone resulting in anticyclonic circulation.

Thus the low pressure around Indonesia and South East Asia invites wind from this direction and the long passage of this wind over water mass makes it rain-laden. Subsequently, we have rainfall in these regions. On the contrary, the low pressure associated with the warming of the ocean current and consequent high pressure over Indonesia and South-East Asian region inhibits any cyclone or depression formation over Indonesia or the Bay of Bengal. Not only has the el niño an effect over this region but it has disastrous consequences elsewhere.

The normal duration of the southwest monsoon is about 100 days beginning from June 1. With the advent of autumn, there is transition from wet season to the dry.

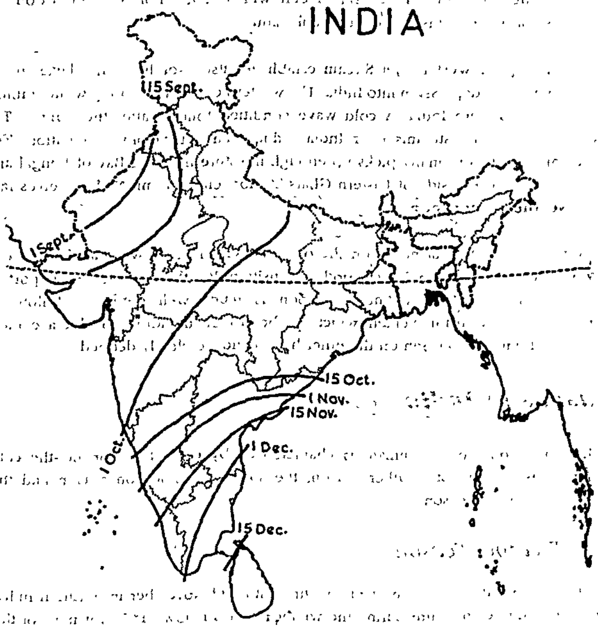
Autumn and Retreating Monsoon

During this season, the monsoon low pressure trough becomes weaker in the northern plains and shifts southwest across India. It brings rain to the south of the Peninsula (which had little in summers) The weakening of the monsoon trough, the gradual establishment of the southern branch of jet stream leads to the withdrawal of monsoon. It begins to withdraw from the northwest India by the end of October (Fig.4 15). The withdrawal is a more gradual process than its onset. The retreat of the monsoon is marked by clear skies and rise in temperature. The land is still moist, owing to high temperature and humidity and the weather condition is highly oppressive. This is known as "*October heat*"

as, the jet stream is now not over it.

The low pressure condition which once prevailed over Northwestern India gets transferred to the centre of the Bay of Bengal. The conditions are ripe for the formation of tropical cyclones over the warm waters of the Bay of Bengal. This coupled with the replacement of **southwesterly** airflow by Easterly winds aloft enable the severe tropical cyclones to cross the eastern coast of southern Peninsula and West Bengal. Occasionally, these tropical cyclones are very destructive. The deltas of Krishna, Kaveri and Godavari are all preferred target of these cyclones year after year. The Coromandal coast receives bulk of its rainfall from these cyclones.

Fig. 4.15. Normal Dates of Withdrawl of Monsoons



Winters

Gradually, the ITCZ moves to its position south of equator, the westerly Jet Stream reappears, high pressure conditions prevail and winter drought returns. The winds blowing outwards from the high pressure zone as they pass over the Bay of Bengal pick up enough moisture These rain laden winds called northeast monsoon are responsible for winter rains in coastal Tamil Nadu.

The Subtropical Westerly Jet Stream establishes itself south of Himalayas again. They bring western depression into India. The western depressions bring winter rainfall over most of northern India. A cold wave condition follows after these rains. The subsidence of the jet streams over India induces an anticyclonic circulation. The anticyclonic circulation finally picks up enough moisture from the Bay of Bengal and pours it on the eastern side of Eastern Ghats. Almost entire Tamil Nadu receives rain by this **Northeast monsoon.**

As with the Southwest monsoon the onset of winter rains over Tamil Nadu is a gradual process beginning with a period of transition. But there is one very important difference, the onset of summer monsoon is much well defined-it follows a progressively northward movement which can be discerned with reasonable accuracy. The onset of winter monsoon on the other hand is not so clearly defined.

Seasons of India

The monsoon type of climate is characterised by distinct seasonality-the cold weather season, the hot weather season, the southwest monsoon season and the retreating monsoon season

Cold Weather Season

The cold weather season normally begins with mid November in northern India The mean daily temperature during the winter remains below 21°C over most of the northern India, the night temperatures are quite low and very often drops below the freezing point. The weather is dominated by high pressure conditions over the northwestern part of the plain. The temperatures are quite low during the winter months over the Indian subcontinent. January and February are the coldest months but the

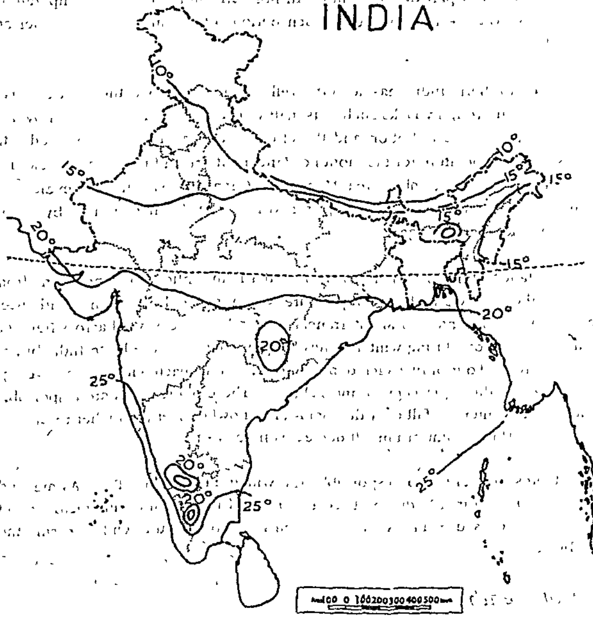


Fig.4.16. The Isotherms of cold weather

coastal areas are exempted from all this. The coastal areas do not register any significant change in temperature. The coldest months in the interior of the Peninsula are December and January with mean daily temperature varying from 28°C in the Peninsular region to 19°C in the Northwest (Fig 4.16). However, there is a large diversity in the mean daily winter minimum temperature which vary from 24°C in the Peninsula to 5 °C in the northwestern part of the country. In northern India, the night temperatures sometimes go below the freezing point. Such periods of unusually cold weather are called "cold waves"

While the northern India has a very well defined cold weather season. The Peninsular India thoroughly lacks such seasonality. The coastal areas hardly show any pattern of temperature distribution and the effect of oceanicity is well marked. The mean maximum temperature for the month of January at Trivandrum is as high as 31°C and for June it is 29.5°C Mumbai, Goa, Mangalore, Chennai, Vishakhapatnam all show a similar pattern of temperature distribution and is obviously characterised by a very small diurnal and annual range.

An important feature of winter season in India is the inflow of depressions from the west and the north west. These low pressure systems called the western disturbances originate in West Asia and over Mediterranean Sea and travel eastward across Iran and Pakistan to reach India during winters. These depressions are stirred into India by the westerly jet stream. Four or five such depressions visit India each winter on an average being most active during December and February. These depressions are responsible for much of the winter rainfall over the plains and snowfall over the higher reaches in the Himalayas The amount of rainfall decreases from west to east.

The depressions are also responsible for winter rainfall in NE in Assam and Arunachal Pradesh Tamil Nadu coast receives most of its rainfall during October and November It is caused mainly by winds which pick up moisture while crossing the Bay of Bengal.

The Hot Weather Season

The north Indian region experiences a well defined hot weather season from April to June. Temperature rises from the middle of March and continues rising. By the middle of May the mercury touches 41°C to 42°C but the heat is reduced by the locally formed dust storms. ***Loo*** is a strong hot wind that blows during day time over northern and

northwestern India. There is a wide variation in the temperature pattern from region to region. It rarely goes below 27°C and may be as high as 45-47°C in some areas. the heating of the sub-continent attracts the ITCZ northwards occupying a position centred at 25° N in July. The location of the ITCZ attracts a surface circulation of the winds which are southwesterly on the west coast and north-northwesterly along the Bengal coast.

Although south India does not have any hot weather nevertheless the temperature is very high above 37°C in many places in south and central India but it never goes below 20°C (Fig 4.17).

The hot weather season is generally dry over north India and without any rainfall. Whatever little amount of rainfall that comes, causes by the way of dust storms or thunderstorms. In general the total amount of rainfall is less than 25 cm. over Rajasthan, Gujarat and Madhya Pradesh. It varies from 50 to 14 cm. in the sub Himalayan districts of Northwestern India, Uttar Pradesh, Bihar, West Bengal, Orissa and greater part of the Peninsula. In Kerala it is more than 25 cm. and over 50 cm. in Assam.

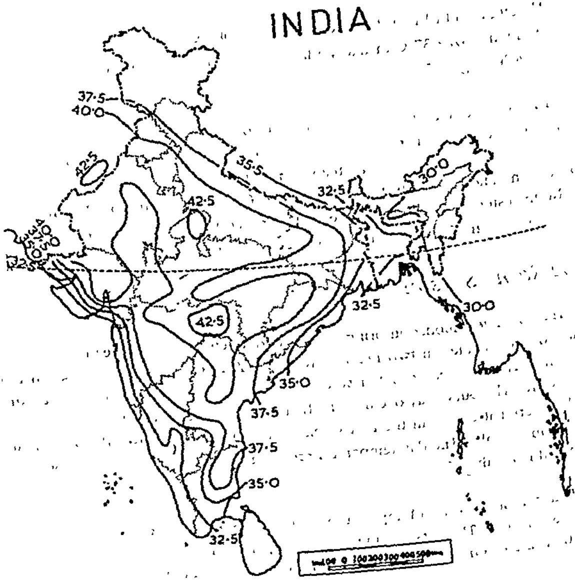
The Rainy Season

The southwest monsoon brings about a complete change of weather in India The S.W monsoon comes in two main currents-the **Arabian Sea** and the **Bay of Bengal currents**. The rains come rather suddenly. This sudden onset is called **"the Burst of Monsoon"**. The burst may occur in the first week of June, in coastal areas even earlier In the interior it comes in the first week of July. The burst causes the temperature to lower substantially. The day temperature registers a decline of 5°C to 8°C between mid June and mid July.

With the onset of rain temperature starts falling even though at many places June is extremely hot. There is a wide spatial variation in the amount of rainfall. These variations are of utmost importance for the Indian agricultural economy.

The southwest monsoon is the major supplier of rain to the Indian subcontinent. The Arabian Sea branch causes rainfall all along the west coast, Western Ghats, Maharashtra, Gujarat and parts of Madhya Pradesh. The Bay of Bengal branch causes rainfall throughout northeast and in Bengal, Meghalaya Plateau before being deflected towards the west and Northwest moving over the northern plain parallel to the axis of

Fig. 4.17. Mean maximum temperature (May)



the Himalayas. Both the Bay of Bengal branch and the Arabian Sea branch meet over the Punjab and the adjoining Himalaya.

The average rainfall over the North Indian Plain generally remains between 100 and 200 cms during this period. The general feature of the monsoon rainfall goes on decreasing with distance from the sea. Calcutta receives 119 cm, Patna 105 cm, Allahabad 76 cm and Delhi 56 cms.

In southwest monsoons there are frequent breaks or spells of dry weather. These breaks are related to the inflow of the tropical depressions which have a fluctuating pattern. These frequencies determine the amount and intensity of monsoon rainfall.

During southwest monsoon one area, in the eastern coast of India particularly in Tamil Nadu remains dry. This is because the Tamil Nadu coast lies in the rainshadow area of the Western Ghats and is parallel to the Bay of Bengal branch.

The Retreating Monsoon

By the second week of September the southwest monsoon begins to retreat. The retreat is very gradual and stands out total contrast to the 'burst' which is sudden. The retreat also shows regional variations. The weather during the season is characterised by high day temperatures but a pleasant nights with mean minimum temperature going down to 20°C or even lower than that, therefore the diurnal range of temperature is high. Severe cyclonic storms develop during this season in the Bay of Bengal which move in a south-easterly to north-westerly direction bringing substantial amount of rainfall on the eastern coast.

Why is Thar a Desert

The Thar is basically a extension of the Iranian and the Arabian desert. The annual rainfall over the Thar desert is less than 15 cms spread mostly over the western districts of Rajasthan. The Thar desert is under the spell of the Arabian sea branch of the monsoon from the month of July to September. The moisture of the air over Rajasthan is high but the rainfall figures are disappointingly low.

The basic reason for the desert and Semi-arid condition is a marked absence of rain generating weather system and an absence of humid airstream. But there is

no absence of humid air over the Thar desert as the region is covered by monsoonal winds every year between June and September. So the desert condition must be associated with *the absence of rain generating weather systems.*

The monsoon circulation is marked by a region of ascent over northeast India and a zone of subsidence over northwest India. *It is this pattern of subsidence over* Rajasthan that is responsible for the formation of the desert condition over Rajasthan. The subsidence is the result of cooling over northwest India. In the northeast India warming is largely the result of latent heat released by heavy rain. This type of warming is absent over northwest India. It can be expected that cooling over northeast *India* is largely the result of outgoing long wave *radiation.* But the estimates of cooling by radiation reveal that cooling could only be about 1.6 to 1.8° C per day by this process. However, to cause subsidence, cooling must be 2.4°C. *per day and indeed the rate of cooling as measured by instruments is* 2.4°C per day. How can the additional rate of cooling of about 0.8°C per day can be accounted for?

The additional amount of cooling could be attributed to the presence of dust over the desert. There is a deep and dense layer of dust over the arid region of Rajasthan. These particles of dust are very small having a diameter of the order of millionth part of a meter. These dust particles do not have their source in Rajasthan. *Had it been so,* then there must be fairly strong current of *ascending* air to lift particles to a height 5 kms. or more. This precisely is the mechanism for rain formation. Obviously then, a large portion of the dust over the Thar desert was transported from the desert of Arabia to *the west of the Thar.*

flux at the top of the cloud is the difference between the upward flux from the cloud top and downward radiation *from the atmosphere above the cloud.* The net result is overall cooling. Cooling in turn promotes subsidence and formation of an inversion layer which prevents vertical ascent and consequently rain *formation* inspite of the presence of a moisture laden air.

Traditional Indian Seasons

The division of the year on meteorological grounds has hardly any significance for the general population. The common man's view of seasons has developed on the basis of his practical experience and his age old perception of the weather phenomena. According to Indian Convention the year is divided into six seasons (*"ritu"*)

Seasons	Months (Indian Calender)	Months (English Calenda
Vasant	Chaitra-Baisakh	March- April
Grishma	Jyeshtha-Asad	May-June
Varsha	Sravan-Bhadra	July- August
Sharada	Aswin-Kartik	September-October
Hemanta	Margshirsha-Pausa	November- December
Shishira	Magha-Phalgun	January- February

The year begins with Vas ... rresponds to the Spring season but it does not ... March and April as it extends over the period mid February to mid April. After Vasanta, occurs the Grishma during Jyeshtha and Asadh (mid April to mid June). The Varsha Ritu (the Rainy Season) comes after the Grishma Ritu and extends over Sravana and Bhadra (July-August). The rainy season ... May and June and continue upto the middle ... in different in different parts of the country.

In Aswin-Kartika (mid September to mid November) the Sharada Ritu occurs. Sharada is transitional between the Varsha and the following Hemanta (Margashirsha-Pausa). During the Hemanta the cold weather intensifies and this is the distinguishing factor with Sharada.

The Shishira which follows Hemanta falls in Magha and Phalgun (January-February). The Shishira gradually gives way to Spring.

This view of seasons holds good only in north and central parts of India which have well defined seasonality.

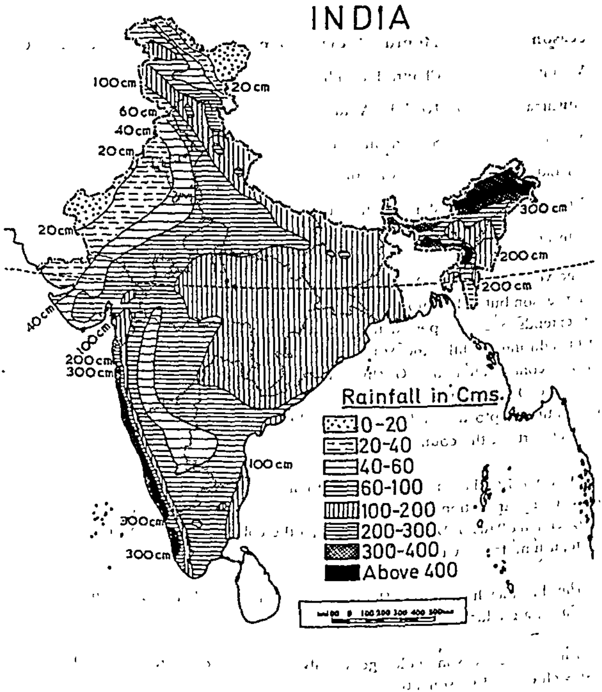


Fig.4.18. Distribution of annual rainfall in India

Annual rainfall distribution

The distribution of rainfall in India is quite uneven and the regional variations are apparent (Fig 4.18). The highest rainfall occurs along the west coast, on the Western Ghats, over Sub-Himalayan regions in the NE and the Meghalaya (Khasi, Jaintia and Garo) hills. The rainfall generally is above 200 cms everywhere and in certain parts of the Khasi and Jaintia hills the rainfall exceeds 1000 cms. It, however, drops to 200 cms or even below in the Brahmaputra valley and the adjoining hills.

Along the western coast, the high rainfall regions are linearly arranged which are in decreasing order as we go away from the coast.

The larger part of the Gangetic Plain and the Central uplands receive a moderate amount of rainfall. The 100 cm isohyet tends eastwards passing over the southern parts of Jammu and Kashmir, Himachal Pradesh and northern Uttar Pradesh. To the east of Allahabad, it bends to the west passing over Bundelkhand in Uttar Pradesh. Turning west-southwestward it covers Madhya Pradesh and eastern Maharashtra and northern Andhra. The region lying to the west southwest have a generally deficient rainfall. In south the isohyet of 100 cms rainfall runs southward from the Gujarat coast roughly parallel to the Western Ghats upto Kanyakumari. Towards east there is an abrupt decrease of rainfall and this drops to below 60 cms.

To the west of the 100 cm isohyet in the north there is a gradual and steady decline in the amount of rainfall towards the Thar desert.

The rainfall over parts of Punjab-Haryana, northern and western Rajasthan, and Kachchh and Kathiawar region of Gujarat is below 60 cm and in the dry region of Rajasthan it is below 20 cm. A narrow strip of land in the lee of Sahyadris is lying in the rain shadow area has below 60 cm of rainfall.

In general two main trends in the distribution of rainfall are discernible

1. From Bengal and Orissa coasts it steadily declines towards the west and northwest.

2. On the west and east coasts it shows a declining trend towards the interior of the plateau.

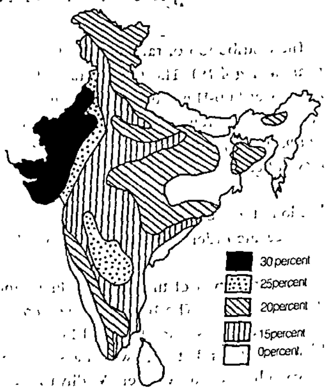
Not only does the annual rainfall varies from place to place (spatially) there is wide variability from year to year as well The actual rainfall of a place in a year may deviate from its mean rainfall by 20 to 50 per cent.

The variability of annual rainfall can be computed with the help of following formula:

$$C = \frac{Standard\text{-}deviation}{mean} \times 100$$

The values thus derived are called **coefficient of variation.** They indicate the amount of fluctuation recorded by rainfall over a long period of time from the mean values (Fig4.19)

Fig.4.19: Variability of rainfall in India



The coefficient of variation of annual rainfall generally ranges between 15 and 30 per cent. As a general rule higher is the amount of rainfall lower is the coefficient and vice versa

A lower than 15 per cent coefficient of variation is found along the west coast, the sub Himalayan belt including Sikkim and Arunachal Pradesh and Northeastern hilly regions of Nagaland, Manipur and Mizoram. From the west coast to the interior of the plateau the variability increases and over the regions of Maharashtra, Karnataka and Andhra Pradesh it is as high as 30 per cent. The 30 per cent variability line (Isopleth) runs over southern Gujarat, western Madhya Pradesh and central Uttar Pradesh. Barring the Himalayan and the sub-Himalayan region, all the places lying to the west and northwest of this line are characterised by high annual variability (over 30 per cent). Over Rajasthan and Gujarat the variability is over 40 per cent. The desert areas of Rajasthan, Kachchh and Gujarat have a still higher variability, i.e., between 50 and 80 per cent. The variability determine to a large extent the incidence of drought in the country. Regions having higher variability are more prone to drought than the region having low variability.

Weather Forecasting in India

Indian economy is very much dependent on the monsoons. The success and failure of the Indian agriculture and consequently the cascading effect is transmitted throughout the economy. In such a condition, prediction of the monsoon becomes a necessity. If the expected average weather does not prevail it often leads to economic loss and discomfort. In the agricultural sector alone 100 mha of land are totally dependent on monsoon rains.

Realising the importance of weather forecast in agriculture a separate Department of Agriculture, Meteorology or Agromet was set up under the Indian Meteorological Department (IMD) in [illegible] forecasts of varying duration keeping the [illegible] target group.

India has done pioneering work in weather forecasting. There are essentially three types of forecast :

(i) Short Range forecast (for 48 hrs.)

(ii) Medium Range Forecast (3 to 10 days)

(iii) Long Range Forecast (More than 19 days)

Short range forecast is essentially based on operational numerical weather prediction methods which has been recently introduced by the IMD following installation of *computers and speedy telecommunication systems*. This is an objective method of weather prediction based as it is on the principles of atmospheric physics; it takes into accounts the current stable weather in a fairly large number of synoptic stations of a given region.

The IMD gets weekly averages of various meteorological data like cloud amount, wind velocity and direction, maximum and minimum mean temperatures, relative humidity, *etc.*, from weather forecasting unit. The data is then analysed and forecast for the next two days. Further remotely sensed INSAT pictures of India and neighbouring countries showing cloud patterns and low pressure areas are regularly available. With these facilities IMD has advanced considerably in its accuracy and in the coverage of the country for short term weather prediction.

It is now possible to clearly demonstrate spatially, the areas which are currently under the influence of the monsoon clouds and the areas to which clouds are advancing. Fairly accurate forecast of cyclones, heavy rainfall or other such disasters are now given for various regions on an operational basis. However, it is the long range forecast that predicts the monsoon. For long and medium term weather forecasting the government has set up a National Centre for Medium Range Weather Forecasting (NCMRWF). A supercomputer has been installed at the centre.

In 1989, the team of Dr. V. Gowarliker developed a new LRF technique comprising parametric and power regression models (PRM) which takes into account the influence of a total of 16 parameters - both local and global. These parameters include wind pattern recorded in the winter, the Eurasian snow cover of December, the central Indian temperature of May, the zonal wind pattern of January, the el *niño* of the previous and the current year, the Darwin pressure in Spring the Himalayan snow cover between January and March and other variables. However, the PRM technique has its shortcomings

(a) There are too many variables and factors in the atmosphere that often mar the accuracy.

(b) It is essentially a statistical calculations and has all the shortcomings of that exercise. It becomes statistically much weaker with a larger number of variables. The negative and the positive influences each get so hazy that it is impossible to zero in on the critical parameters in relation to the weaker zones.

(c) The model also does not identify a set of independent variables (each is dependent on another), for example, the pressure at Darwin is influenced by and influences the southern oscillation index and together these are not independent of the el niño.

(d) It is very general model and cannot predict the regional distribution of rainfall.

(e) The definition of the term normal is + 10 per cent and since Northeast almost always has high rainfall the deficient pockets equalise this prediction.

However, with the advent of new technologies and a better understanding of the global atmospheric circulations, the predictions are bound to improve.

Climatic regions of India

The essential characteristics of the climate of India is always tropical in nature. However, the combination and distribution of the various elements of climate reveal many regional pattern. These regional patterns thus formed are more or less homogenous in character broadly with respect to temperature, moisture and rainfall conditions. The division of climates into broad homogenous types is not very easy and requires intricate methods mostly statistical to group it into simple index. Many climatic factors for this purpose are taken into account such as temperature-its diurnal and annual range, precipitation- its quantity, seasonability and frequency, evaporation and transpiration and the vegetation types which are reflective of a particular climate. Based on these postulates there have been attempts to divide India into climatic zones Most notable of these attempts are from Koeppen, Thornthwaite and Trewartha.

Koeppen' scheme

Koeppen based his classification on the nature and type of vegetation which is determined by climatic factors like temperature and rainfall. Based on his scheme India can be divided into the following climatic types (Fig 4.20).

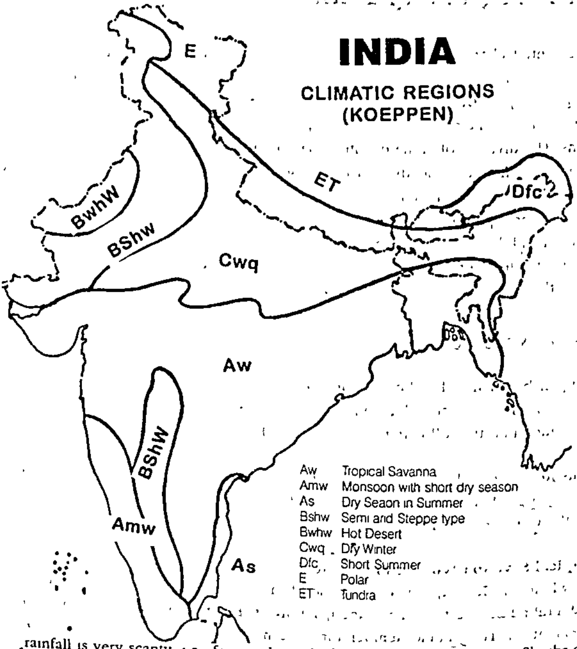
1. **Monsoon type** with short dry season (AmW). This region comprises the western coastal strip where the rainfall exceeds 120 inches. The dry weather is very short and the vegetation is chiefly of evergreen type.

2. **Tropical Savanna type (AW)**. This region includes almost the entire Peninsula, the whole of Gujarat, Maharashtra, south and central Madhya Pradesh, Orissa, Andhra Pradesh, western Tamil Nadu, southwest Bengal, southern Bihar, and parts of Karnataka. The summer temperatures are high and the rainfall is from 30 to 50 inches.

3. **Monsoon Type** with dry season in high sun period (AS). comprises of the coastal strips of southern Andhra Pradesh and eastern Tamil Nadu. The rainfall comes mainly in winter from the retreating monsoon and is moderate 30-40 inches

4. **Semi-arid Steppe climate (BShW)**. occupies parts of Rajasthan, southwestern Punjab and parts of Karnataka and Maharashtra. The summers are dry and the

Fig.4.20. Koeppen's classification of Indian climate



rainfall is very scanty, i.e., four inches which comes mainly in winter. Shrubs and thorny bushes characterise the vegetation

5 Hot Desert type

6. **Monsoon type** with dry winter embraces the whole of Sutlej, Ganga plain and parts of Malwa plateau. Wet Summers

7. **Cold humid winters** with short summers cover the whole of northeast India

8. Polar type covers the whole of Kashmir and Laddakh plateau. Snowfall is very frequent in winter and the warmest months temperature varies from 0° to 10°C.

Thornthwaite's Scheme

Thornthwaite based his classification on the water balance-evapotranspiration, as he called it on the basis of the method to calculate the monthly value of water surplus and water deficit. He linked areas having water surplus and water deficit. The water deficit areas had thus arid climate while water surplus areas had humid climate. On the basis of Thornthwaite's scheme the following climatic regions can be identified

1. The **perhumid region** which lies along the west coast of India, south if Goa and parts of northeastern India.

2. The **humid climate** is found in the adjoining regions of humid region of Northwestern Bengal and the neighbouring parts of Northeastern India

3. The **moist Subhumid type** of climate is found in parts of Western Ghats, Orissa and West Bengal.

4. The **dry Subhumid type** of climate spreads over Ganges valley and Northeastern parts of central India

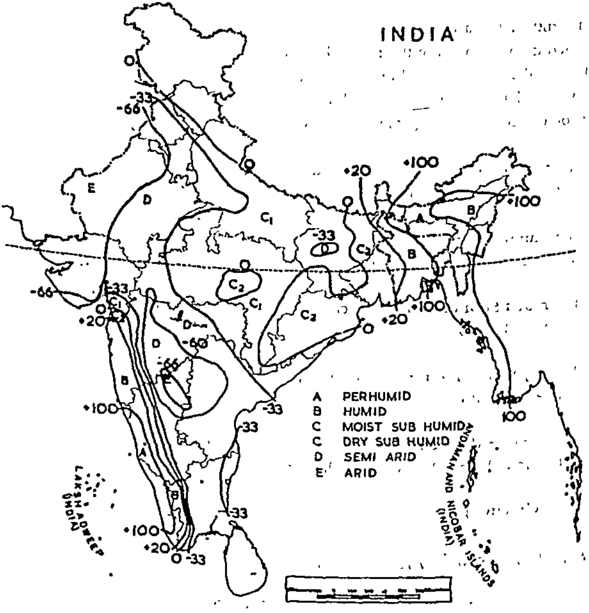
5. The **Semi-arid type** of climate is found in the interior of the Peninsula, western Uttar Pradesh and Madhya Pradesh, Haryana and Punjab.

6. **Arid climate** spreads over Saurashtra, Kachchh and Rajasthan.

Trewartha's scheme

Besides these two schemes of climatic classification, one classification was proposed by Trewartha. It is modified form of Koeppen's classification and is thought to apply to Indian conditions most appropriately since it broadly corresponds with the physical aspects of Indian geography, it's vegetation cover, soil and broad natural regions of the country, which closely corresponds with the agro climatic zonation. The tropical

Fig.4.21. Thornthwaite's scheme of climatic classification



rainforest region, the tropical Semi-arid steppe climate, tropical and Subtropical steppe, tropical desert, humid Subtropical with dry winter and mountain climate are the seven regions into which he divided the country. However, all these divisions are only sub type of the climate which can be described as monsoonal type of climate

1. Tropical Rainforest (Am)

Distribution western coastal plain, Sahyadris and in parts of Assam

Temperature: Minimum 18°C during winter and maximum 29°C in April-May

Rainfall: Average annual rainfall 80" rainfall from southwest monsoon, which breaks easily and lasts long.

2. Tropical Savanna (Aw)

Distribution Most of the Peninsula except the Semi-arid zone in the lee side of the Sahyadri. Marked by long dry weather lasting through winter and early summer.

Temperature: Above 18°C during winter and above 32°C in summer. Southern areas experience more equable temperature regime than the areas farther north.

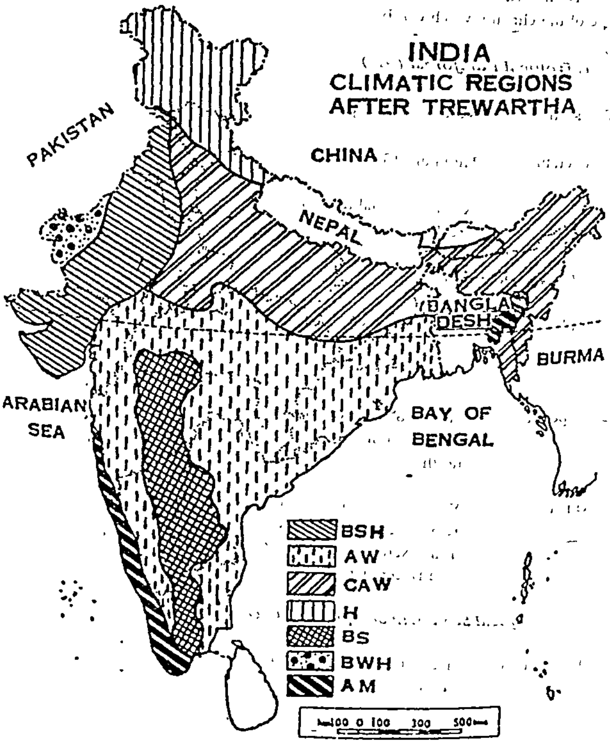
Rainfall: Varies from 30 inches in the west to 60 inches in the east. Northern region receives most of the rainfall from southwest monsoon In Tamil Nadu half of the amount comes from northeast during October and December.

3. Tropical Semi-arid Steppe Climate (Bs)

Distribution Rain shadow belt running southward from Central Maharashtra to Tamil Nadu in the lee side of Sahyadris and Cardamom hills

Temperature Varying from 20-24°C for December (coldest) and 33°C for May (hottest).

Fig.4.22.Trewartha's scheme of climatic classification



Rainfall 15 inches to 30 inches. The rainfall is erratic and uncertain Southwest monsoon principal source

4. Tropical And Subtropical Steppe (Bsh)

Distribution Broad crescent from Punjab to Kachchh between the Thar desert in the west, Ganga plain in the east and Peninsula in the south

Temperature Average temperature is 27°C. Minimum 12°C in January and 35°C maximum in June. Maximum temperature recorded is 48°C.

Rainfall Annual average rainfall 11 inches. Highly erratic varies from 11 inches to 24 inches. Monsoon failure and drought common.

5. Tropical Desert (Bwh)

Distribution Western parts of Barmer, Jaisalmer and good parts of Kachchh form the sandy wastes of Thar.

Temperature Average temperature is 34.5°C. Highest 48°C in summer to lowest 12°C in winter. Temperature decreases towards north in winter, i.e., very high diurnal and annual temperature.

Rainfall Average annual rainfall is 11 inches, very high spatial and temporal variation. Whether it rains it is in the form of cloud burst taking place mostly in July- September. When the southwest monsoon may penetrate the region. Sandstorm in the afternoon and hot and dry winter winds blow practically throughout the day.

6. Humid Subtropical With Dry Winter

Distribution Large area to the south of Himalaya, eastern Rajasthan, plains of U.P and Bihar, N. Bengal, parts of Assam and Arunachal Pradesh.

Temperature More 46-48°C. Mild to severely cold winters. Summers hot in western part and mild in east (equable).

Rainfall	Annual rainfall varies from 25 inches to 100 inches received mostly from southwest monsoon. Rainfall increases towards east and north where it is humid. Dry winters. Western parts receive little rain from westerly depression.

7. *Mountain Climate (H)*

Distribution	Himalayan and Karakoram ranges above 6000 m.
Temperature	Sharp contrast between the temperatures of the sunny and shady slopes, high diurnal range of temperature and variability of rainfall. Maximum temperature 15-17°C in summer and below 0°C in winter
Rainfall	3-4 " on northern slopes and 100 on western slopes. Climate slightly better on southern slopes, amount of rainfall increases towards east. in are accompanied by strong of cold air that emanate from a large anticyclone located over Siberia and the adjoining parts of China.

Important Words

Monsoon
Depressions
Inter Tropical Convergence Zone
Cold Waves
Burst of Monsoons
El Nino
Loo
Oceanicity
Anticyclonic
Monsoon Low Pressure Trough
Meridional Circulation System
La Nina
Coefficient of Variation
Jet Stream
Orographic
Norwesters
Mango Showers
Typhoons
Findlater Jet Stream
Isopleth

5

From Green Book
IX

VEGETATION

Introduction

The climate of India is essentially tropical and even in the northern region of Punjab plain winters are mild. Consequently, vegetation is of a tropical monsoonal character throughout India below a height of 900 m. Variations in species and luxuriance of vegetation from place to place thus depends largely on distribution of rainfall. Many scholars including H. G. Champion, Seth, Carltroll and G. S. Puri have added to our knowledge of Indian vegetation (Fig 5.1)

India can be classified into sixteen different groups of vegetation.

1. Tropical Wet Evergreen Forest
2. Tropical Semi Evergreen Forest
3. Tropical Dry Evergreen Forest
4. Tropical Moist Deciduous Forest
5. Tropical Dry Deciduous Forest
6. Tropical Thorn Forest
7. Subtropical Dry Evergreen Forest

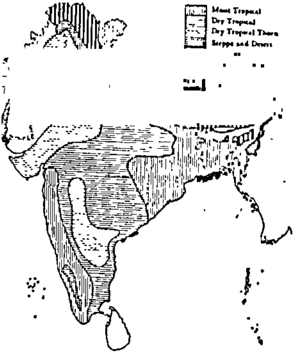
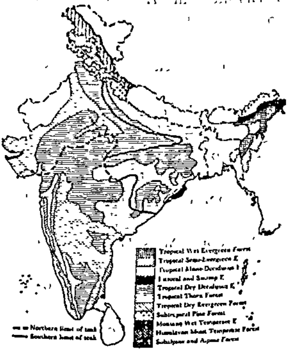


Fig.5.1. Vegetation of India



8. Littoral and Swamp Forest (Including Mangroves)

9. Subtropical Broad Leaved Hill Forest

10. Subtropical Pine Forest

11. Montane Wet Evergreen Forest

12. Himalayan Moist Temperate Forest.

13. Himalayan Dry Temperate Forest.

14. Sub-Alpine and Alpine Forest

Vegetation zones of India

1. Tropical Wet Evergreen Forest

The Tropical wet evergreen forests are found in regions where the annual rainfall is above 250 cms. The dry season is comparatively short, (about 3 to 4 months) and the mean annual temperature is 27°C to 30°C. They are found all along the Western Ghat from Mumbai southwards to Tirunelvelli and in patches covering parts of Tamil Nadu, Karnataka, Kerala, Submontane West Bengal, Coastal Orissa, and in Tripura, Arunachal Pradesh, Manipur, Nagaland, Meghalaya and practically the whole of Andaman and Nicobar island.

Excessive heat and humidity gives rise to luxuriant growth of trees. The growth of vegetation is so profuse that the trees rise high competing with one another and ultimately arrange themselves in three or four stories or tiers. Tiers of trees are covered with climbers and epiphytes (plants growing on another trees). The undergrowth mainly ... ns, the ... . Trees grow very close together and in a single acre hundred different species of trees can be found. As such, these forests are very dense and impenetrable and this, in fact, does not allow light to reach the ground. The ground flora species are few with little grass Since there is abundance of moisture availability, the trees are evergreen and do not shed their leaves in any part of the year. The trees are chiefly of hardwood type. The

important trees are Toon (*Cedrella toona*), Poon (*Calophyllum*), Rosewood (*Dalbergia sp*), Bishopwood (*Bischofia*), Ironwood (*Mesua*), Ebony (*Diospyros*), Chaplas (*Artocarpus sp*), Gurjan, Hopia, Telsur, Pilachampa (*Michelia nilgirica*), Sissoo (*Dalbergia sp.*), Sandal (*Santalum album*), etc.

2. Tropical Semi Evergreen Forest

Where annual rainfall decreases from 250 to 200 cms. evergreen forest degenerate into semi-evergreen forest. The temperature is from 24° to 27° C and moisture is not adequate to keep them evergreen and the deciduous trees increase in number. These forests are found along the Western Ghat from Cochin to Mumbai, in the western coast, upper Assam region, lower slopes of eastern Himalaya, Orissa and adjoining hills and in Andaman and Nicobar Islands

These forests are mixed evergreen and deciduous forest with a tendency towards gregariousness, thicker and rougher barks, with relatively less dense canopy and heavy climbers 'In the upper canopy *Xylia* and *Terminalia* are conspicuous but *Dipterocarpus* also occur *Myrtaceae, Lauraceae* and Bamboos' (*Bambusa*)' Arundinaceae 'and Bpolymorpha form the middle canopy Underground cover is made of evergreen shrubs of *Rubiaceae* and *Canthaceae*. Epiphytic mosses, ferns and orchids are present. Trees with buttressed roots are also found.

The important trees are Aini, Semul, Hopea, Kadam, Laurel, Rosewood, Haldu, Kusum, Champa, Mango, Indian chestnut, etc.

3. Tropical Dry Evergreen Forests

These forests occur in the east coast of the Peninsula, north of Nellore in Tamil Nadu and Andhra Pradesh, where the annual rainfall is about 100 cm. and mean annual temperature 28°C. The rainfall comes mainly from the NE monsoon.

The forests are predominantly evergreen broadleaved with some deciduous trees. The forests are often dense but usually under 20m The important trees found in these regions are *Mimusops elengi, Manilkara hexandra, Dioospyrus ebenum, Strychnos nuxvomica, Memecylon edule, Sapindus emarginatus.*

4. Tropical Moist Deciduous forests

These forests are found in all parts of India having a rainfall of 40-60 inches (100-150 cm.) and a mean annual temperature of 24°C ranging from a maximum of 20°C in the south in coastal regions and 4°C in the north and inland regions. There are four regions where these forests are found :

1. Himalayan foothills, a belt just to the south of the evergreen belt and in Assam.

2. Central plateaus including Chhotanagpur, Upper Mahanadi valley Vindhyan and Satpura hills.

3. A belt running north-south on the eastern slopes of Eastern Ghats, west of the evergreen belt in Maharashtra, Karnataka, Kerala and Tamil Nadu.

4. Hilly areas in the eastern part of the Deccan including Eastern Ghats in Tamil Nadu.

The chief feature of these forests is their leafless existence in the dry season generally in March and April. The trees come into new leaves long before the commencement of the monsoon and many of them are in bloom when almost leafless, e g , *Salmalia malabaricum, Cassia fistula, Erythrina indica, Sterculia sp.*, etc. Others like *Dalbergia sissoo* flower after the appearance of new leaves.

These forests are characteristic of an irregular top storey of predominantly deciduous species 40 m or more high, buttressed roots, existence of a second storey, undergrowth of shrubs including heavy climbers like canes with bamboo growing here and there in patches. Sal (*Shorea robusta*) and Teak (*Tectona grandis*) are the two most important trees.

The typical landscape consists of tall Teak trees with other trees, bamboos and shrubs growing close together so as to form thickets. Besides, there are also open grass patches. The important trees are Arjun (*Terminalia arjuna*), Laurel (*Terminalia tomentosa*), Mulbery (*Morus*), Kusum (*Schleichera trijugu*), Gular (*Ficus glomerata*), Siris (*Abizzia procera*), Haldu (*Adina cordifolia*), Mahua (*Bassia latifolia*). Sandalwood (*Santalum album*), Shisham (*Dalbergia sissoo*), Khair (*Acacia catechu*), etc.

5. Tropical Dry Deciduous Forest

Tropical dry deciduous vegetation is found in regions where the average annual rainfall is between 75 cm and 100 cm These are found in Maharashtra, Madhya Pradesh, Andhra Pradesh, Tamil Nadu and Karnataka, chiefly on low hills. This type of vegetation is entirely deciduous or nearly so. The top canopy is rather light and rarely over 25m high usually 8 to 20m found in many States. The landscape is of parkland type with open formations especially of teak and several other tree species interspersed with stretches of open grass. Enough light reaches on the forest floor to permit the growth of grass; Bamboo is present but its growth is not luxuriant. The climbers are few but some are large and woody

In the south the most characteristic tree is Teak (*Tectona grandis*) associated with *Terminalia, Boswellia, Sterculia* and *Acacia catechu*. The Bamboo growing here is *Dendrocalamus* and the grasses are of medium height such as *Heteropogen, Saccharum spontaneum*, etc.

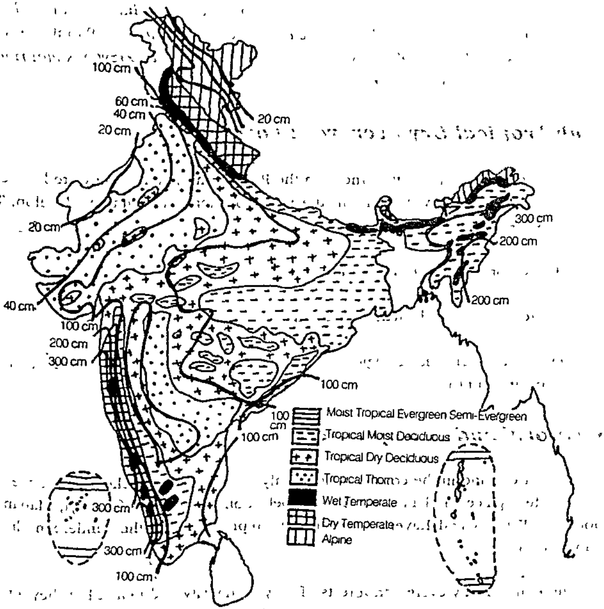
In the northern region the Punjab, Uttar Pradesh, Himachal Pradesh and hilly tracts of Bihar and Orissa the dominant tree is Sal (*Shorea robusta*) and the forests are known as Siwalik hill sal forest and dry Peninsular forest. In summer and before that these forests are completely leafless. With the return of the wet weather the trees and shrubs are thickly covered and the ground is overgrown with shrubs.

6. Tropical Thorn Forest

Tropical Thorn forest are found in areas where the rainfall is 50-75 cms and the mean annual temperature is 25°C to 27°C These forests cover parts of the Punjab, Uttar Pradesh, Rajasthan, North Gujarat and extend in the south to Berar in Maharashtra, Bellary in Karnataka and Cuddapah and Kurnool districts of Andhra Pradesh.

These forests are deciduous with low thorny trees with a predominance of xerophytes. The canopy is more or less broken and the height hardly reaches 10m. The vegetation largely consists of coarse grasses with widely spaced *Acacias* and *Euphorbias* including the typical spiny and thorny varieties: At places clumps of wild palms (*Phoenix sylvestris*) grow here and there. In the central Peninsular region the vegetation chiefly consists of poor grassland with stunted *Acacias* (*Cassistora*) and other shrubs well dispersed throughout In summer the surface is covered by a pale carpet of grass.

Fig.5.2. Vegetation in relation to rainfall in India



In the more drier regions of Rajasthan where the rainfall decreases even further, there are grassy patches and salt marshes Plants are endowed with drought protecting machanism, such as *Cactus* and *Euphorbias* which increases in number.

The most important tree found in this region is *Acacia phulia (Acacia modesta)*, Khair (*Acacia catechu*), *A arabica, A catechurides, A. chunder*, Babul (*Prosopis juliflora*), Kokko (*Albizzia lebbek*) various species of *Zizyphus*, *Zizyphus mauritiana* and many types of fleshy *Euphorbias*

7. Sub Tropical Dry Evergreen Forest

These are found in northwest India, in the Punjab and Jammu. They are low scrub forests of small leaved evergreens. In the monsoon, herbs and grasses develop. The chief types are

(a) Olive Forest with *Olea cuspidata*

(b) Acacia Forests with *Acacia modesta*

They form a very small region where the vegetation is similar to that of the Mediterranean countries

8. Littoral and Swamp Forest

These are found in the coastal regions only in the form of thickets on the western coast of few places and in a continuous belt along the delta of Ganga, Mahanadi, Godavari, Krishna and Kaveri. They are best represented by the sunderbans in the Ganga delta.

These are mainly evergreen forests of varying density and height but they always associate themselves with swampy and water logged conditions or coastal sands and estuarine muds

The trunks are supported by stilt like roots (submerged under high tide) and there is profuse growth of climbers

This type is further divided into five subtypes The subdivision is mainly based on special site and other locality factors which gives distinctive character to subtypes. Ecologically they may be stages in natural succession or edaphic preclimaxes. The five subtypes and the important species found in each subtype is :

(a) Littoral

Almondwood (*Terminalia catappa*)

Sundri (*Heritiera sp.*)

Bulletwood (*Manikara littoralis*)

Poon (*Calophylum sp*)

Gutel (*Trewia nudiflora*)

(b) Tidal Swamp Forests (Mangrove)

Guon (*Excoecaria agallocha*),

Keora (*Sonneratia apetala*)

(c) Fresh Water Swamp

Jarul (*Lagestroemiaspeciosa*), Benati (*Lophopialum wightianum*),

(d) Seasonal Swamp Forests

Arjun (*Terminalia arjuna*), Jarul (*Lagerstroemia speciosa*),

Uriam (*Bischofia javanica*)

(e) Riverine Fringing Forests

Arjun (*Terminalia Arjuna*),

Jarul (*Lagerstroemia speciosa*),

Uriam (*Bischofia javanica*)

9. Sub Tropical Broad Leaved Hill Forest

These forests are essentially found between 1000 to 1700 m. where the mean annual temperature is about 18°C to 21°C and the rainfall about 75 to 125 cms. The rainfall however, varies exceedingly. Mahabaleshwar has a very heavy rainfall of over 600 cm concentrated in about 4 months, while Cunnoor has much less rainfall but with no dry

season. This type is divided into two parts - the Southern Hill Forests found in the Nilgiris of South India, Central India, Rajasthan and Bihar. The Northern Hill Forests are found in the North East India, West Bengal, Assam and other north eastern States.

In the northern regions the trees may attain a height of 50 m. with a middle storey of medium sized evergreens and a shrubby undergrowth. Climbers are numerous. The main trees are species belonging to the genera *Castanopsis schima, Terminalia, Eglehardita*, etc., while in the southern region the main tree species are *Syzygium, Memecylon, Calophyllum, Eanthium, Rhododendron*, etc.

10. Sub Tropical Pine Forest

These forests are found in the Punjab, Uttar Pradesh and Assam and all along the western and central Himalayas extending further into Assam where the rainfall is 150-300 cms These are mixed forests of broad leaved trees and Conifers, vegetation predominantly with Pine associates.

The predominant broad leaved trees are Quercus as associated with Rhododendron, Lyonia, Syzygium, Mallotus, Casa, etc. The Pines are *Pinus roxburghii* in the west, *Pinus khasya* in the east, and *Pinus insularies* (chir and chil). *Quercus incana*, the typical Oak of the western and *Q griffithii* of the eastern Himalaya are found in this type of forest

11. Montane Temperate Forests

This type of vegetation is found in both the south and the north in the Western Ghats and the Himalayas, respectively. These forests differ in their form and composition in north and south but the true montane temperate forest of India is more akin to the flora of eastern Europe than to any other part of Indian subcontinent. The conifer forests of India are also confined to the Himalayas only.

As these forests are located in high altitude mountains, the climatic and edaphic factors such as precipitation, day length, aspect, soil types, drainage, wind velocity, etc. play an important role and control the preponderance, presence or absence of the main tree species in a relatively small area giving rise to forest types and subtypes.

12. Montane Wet Temperate Evergreen forest

These forests occur above a height of 1500 m. where the mean annual temperature is about 11°C to 14°C and a mean annual rainfall between 150 to 300 cms. They are confined to the *Nilgiri*, Anaimalai and Tirunelvelli hills of South India and in the high hills of eastern Himalayas in West Bengal, Assam and Arunachal Pradesh.

These are closed evergreen forests with short bold branchy trees attaining high girth with a height that rarely *exceeds 6 m*. The crowns are dense, the leaves are rounded and the branches are covered by mosses, ferns and other epiphytes, woody *climbers* are common.

In South India the forests are confined to sheltered valleys of the high hills locally called ***'sholas'***. The trees found in shola forest are not found anywhere else in India (*See Box*).

The important trees are Deodar, Indian chestnut, Magnolia, Blue pine oaks, Hemlock, etc. The principal species of Oaks are *Quercus (Q. lamellosa, Q. lineata* and *Q. panchyphylla)*. Associated with oaks are mostly Rhododendrons, specially *R. arborium, Chilauni, Birch, Plum (Michilus)* are other trees.

13. Himalayan Moist Temperate Forests

These forests occur in the temperate eastern and western Himalaya, i.e., along the entire length of the Himalayas comprising Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh and eastward to Darjeeling and Sikkim at an altitude of 1600 to 3500 m.

These are basically evergreen coniferous forests 30 to 50 m. high with mosses and ferns growing on trees. These are quite alike the forests found in North Temperate zone in Europe and America. Among the broad leaved species Oaks are most common. The most important trees are Deodar (*Cedrus deodara*), Fir (*Abies pindrow*), Oak (*Quercus*), Spruce (*Picea smithiana*), *P. spinulosa, Rhododendron arborium*, etc.

14. Himalayan Dry Temperate Forest

These forests are found in Jammu & Kashmir, Punjab, Himachal Pradesh, Uttar Pradesh and some portions of NE India.

These forests are characterised by open formations predominantly with conifer species The usual broadleaved species are of poor height and occur scattered among the conifers. In some places they also occur in pure patches of xerophytic shrubs all over the area.

The important trees are Kali (*Pinus wallichiana*), Indian Oak (*Quercus ilex*) in the west and Kali, Spruce (*Picea spinulosa*) and Birch (*Betula sp.*) in the east.

15. Alpine Forests

Alpine forests are found in the Himalaya and connected ranges. Above the timber limit high forests are replaced by Alpine scrub varying in form with the available moisture supply. In Alpine forests three types are recognised.

Sub Alpine Forests have stunted deciduous or evergreen forest usually in close formation with or without conifers The characteristic species are Spruce (*Picea smithiana*), Fir (*Abies sp*) and Birch.

Moist Alpine scrub are low but often dense scrub having Birch and Rhododendron.

Dry Alpine Scrub are xerophytic scrub in open formation with a preponderance of Junipers (*Juniperus communis* and *J. wallichiana*) in the west and (*Juniperus recurva*) in the east

Table 5.1: Major forest groups of India

FOREST GROUP	TEMPERATURE CONDITIONS RELATED TO		OCCUPIED BY GROUP
	Mean annual temperature	Mean January temperature	Winter
Tropical	Over 24 deg.C	Over 18 deg.C	None-no frost.
Subtropical	17 deg C to 24 deg.C	10 deg C to 18 deg.C	Definite but not severe, frost rare.

Temperate	7 deg.C to 17 deg.C	1 deg.C to 10 deg.C	Pronounced, with frost and some snow
Alpine	Under7 deg.C	Under 1deg.C	Severe,with much snow

TROPICAL GROUPS	Seven groups are recognised	
TYPE	BROAD CHARACTERS	MAJOR TREE TYPES
Wet Evergreen Forest	Dense tall forest, 45 m. Or even higher, entirely evergreen or nearly so. No species occurs gregariously. No individual species form more than 1 % of the upper canopy.	*Dipterocarpus, Actocarpus, Hopea, Dysoxylum* and *Mesua.*
Semi Evergreen Forest	Dominants include deciduous species but evergreens predominate. The general canopy is typically less dense than the true evergreen	*Doltercarpus, Artocarpus,, Terminalia, Albizzia* and *Phoeta*
Moist Deciduous Forest	Dominates mainly deciduous but subdominant and lower canopy largely evergreen. Canopy rarely dense and even but over 25m. high.	*Tectona grandis* (Teak) in south, *Shorea robusta* (Sal) in north, *Albizzia, Terminalia, Lagerstroemia, Gmelina, Pterocarpus* and *Dalbergia.*
Littoral and Swamp Forest	Mainly evergreen, of varying density and height, but always associated with wetness.	*Casuarina, Heritiera, Manilkara* and *Rhysophera.*
Dry Deciduous	Entirely deciduous or nearly so.Top canopy rather than light and rarely over 25 m high usually 8-20 metres.	Teak in south, sal in north, *Anogeissus, Terminalia, Madhuca* and *Diospyros*
Thorn Forest	Deciduous with low thorny trees. Canopy more or less broken. Height under 10 metres.	*Prosopis, Acacia, Caltropis, Salvadora* and *Euphorbia.*

Dry Evergreen Forest	Hard leaved, evergreen trees, predominant with some deciduous emergents, often dense but usually under 20 m. high	*Manilkara* and *Mimusops*
SUB-TROPICAL GROUPS	Comprises three types of groups	
Sub-Tropical Hill Forest	Broad leaved, largely evergreen high forest.	*Calophyllum, Cinnamomum, Castanopsis, Schima* and *Maichelia*
Sub-Tropical Pine Forest	Pine associated predominant	*Pinus roxburghii* (in west) and *Pinus insularis* (in east)
Sub-Tropical Evergreen Forest	Low xerophytic forest and scrub	*Olea cuspida* and *Acacia modesta*
TEMPERATE GROUPS	Comprises three types of groups	
Montane Wet Temperate Forest	Evergreen forests without conifers	*Temstroemia* and *Michelia* in southern hills, and *Qercus* (Oak), Acer, Alnus and *Machilusu* in the Himalayas.
Himalayan Moist Temperate Forest	Evergreen forest mainly Oaks and Conifers	*Cedrus deodora* (Deodar), *Abies pindrow* (Fir), *Quercus* (Oak), *Picea* -*smithiana*- (Spruce).
Himalayan Dry Temperate Forest	Open coniferous forest with sparse xerophytic undergrowth	*Pinus wallichiana, Pinus gerardiana* and *Quercus ilex in west,* and *Picea spinulosa, Pinus wallichiana* and *Betula* in east.
ALPINE GROUPS	These are only in the Himalaya and connected ranges. Above the timber limit, high forests are replaced by Alpine scrub varying in form with the available moisture supply. Three types of groups are recognised.	

Sub-Alpine Forest	Stunt deciduous or evergreen forest, usually in close formation, with or without conifers.	*Picea smithiana* and *Abies spectabilis* in west and *Abies densa* and *Betula utilis* in east.
Moist Alpine Scrub	Low but often dense scrub	*Betula utilis* and *Rhododendron campanulatum*.
Dry Alpine Scrub	Xerophytic scrub in open formation	*Juniperus cummunis* and *Juniperus wallichiana* in west and *Juniperus recurva* in east.

The Himalayan Vegetation Transition

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The Himalayan mountain system extends for about 3000 km. from north west to south east and its vegetation belts can be explained by transitions from north to south, from east to west and from lowland to mountain top. The southern slopes and ranges are exposed to the rain bearing winds and are densely forested. Forests change on the Tibetan side of the mountains to cold high mountain steppe lands. In the same direction the Alpine tree line rises from 3400-3000 m, in the outer southern ranges to 4400- 4600 m. in Tibet. The zone of perpetual snow begins at 4500-6000 m. in the south and at a maximum of 6400 m. in Tibet.

Schweinfurth (1984) has made a distinction between outer, inner, and Tibetan Himalaya in a north-south transition. The character of inner Himalaya is determined by local condition [illegible] deep valleys in the east and Ka[illegible] Sikkim represents the wet part th[illegible] valleys of Lachen and Lachung is Inner Himalayan; and the high valley of Lhonak is Tibetan Himalayan. Thus, Sikkim displays the differentiation between outer, inner and Tibetan Himalayas.

Another transition is from southeast to northwest direction in the foothill zone from near tropical rainforest in Assam to semi desert conditions in parts of the northwest (Fig SB1.1). Thus, the lowlands in Assam and Bengal as far as Bhutan are covered with tropical evergreen rain forests. This gradually changes westwards in Sikkim

and Nepal to tropical humid deciduous forests (sal forests). From west Nepal to the Sutlej a drier semi humid type of deciduous Sal forest occurs. In the much drier Punjab, the natural vegetation is sub tropical semi arid thorn steppe and in the valleys of the extreme north west towards the Hindu Kush and the Karakoram semi-desert conditions give way to Asiatic Artemesia steppe above 2000 m.

Carl Troll (1972) has prepared a subdivision of Himalayas into seven natural sections.

1. The Tsangpo Himalayas, the mountain ranges and valley of southeastern Tibet.

2. The Assam Himalayas

3. The Sikkim Himalayas from Bhutan through Sikkim to eastern and central Nepal.

4. The Garhwal Himalaya from western Nepal through Kumaun and Garhwal to the Sutlej.

5. The Punjab Himalaya from the Sutlej to the Indus.

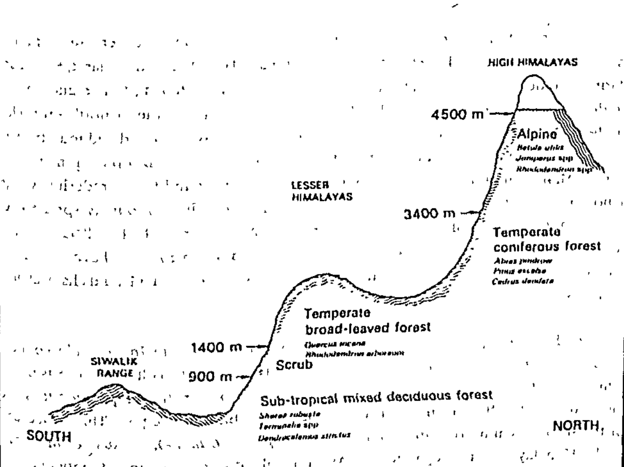
6. The Indus Himalaya

7. The Tibetan Himalaya

In all these regions there is a distinct vertical gradation of climate and vegetation (Fig. 5B.1). In the east tropical rainforest is followed by evergreen lower montane forest, evergreen upper montane forest, subalpine Rhododendron forest and at higher levels by wet alpine scrub and meadows. In the western part of the central Himalaya the tropical deciduous forest gives way to *Pinus roxburghii* forest, followed by mixed Oak and Coniferous forest, subalpine forest of Birch (*Betula utilis*) and moist alpine scrub and meadows.

In the drier north west, the sequence ranges from thorn steppe along the foothills into evergreen sclerophyllous forest, *Pinus roxburghii* forest, mixed oak and coniferous forest, subalpine forest of Birch and moist alpine scrub and meadows.

Fig.5B1.1. The Himalayan Vegetation Transition



As conditions become even drier the sequence ranges from the semi desert of the valleys through *Artemisia steppes* and steppe forest of *Pinus gerandiana* and *Quercus baloot* into western Himalayan forest to subalpine forest of Birch (*Betula utilis*) and moist alpine scrub and meadows. In the extreme northwest there is no moist vegetation type and dry vegetation types of semidesert valley floors lead into Artemisia steppe and into the alpine steppe of the Tibetan plateau.

However, there are a number of interesting variations created by local topography, climate and geomorphological processes. The descending winds in the deeper valleys create dry vegetation on the valley floor and lower slopes in contrast to wet vegetation at higher elevation in the belt of cloud forest. Contrast also occurs between north and south facing slopes. Slopes prone to frequent snow avalanches ... tracks. Conifers get replaced

Distribution of Forests

The distribution of forests in the mainland of the country is very uneven. The Indo-Gangetic plain has little forest. Major portions of Uttar Pradesh, Gujarat, Rajasthan, Madhya Pradesh, Bihar, Karnataka and some parts of West Bengal, Orissa and Andhra Pradesh are covered by tropical dry deciduous forests. The whole of north Arunachal Pradesh, Nagaland, Meghalaya, Manipur and Tripura have moist deciduous type of forest except Arunachal Pradesh which has some areas under subtropical pine forests. Kerala, Maharashtra, Madhya Pradesh, Orissa, West Bengal and Uttar Pradesh have the major portion of moist deciduous forests The Tropical thorn group is spread over Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu and to some extent in Uttar Pradesh. Kerala and Andaman and Nicobar islands have large areas under evergreen forests while Lakshadweep, Minicoy and Amindivi Islands have almost no forests

Broad leaved species constitute 93% of the total forests in India while conifers account for only 7% An interesting aspect is the location of broadleaved forests in the temperate latitudinal zone, yet from the point of view of floristic composition they are more akin to the flora of tropical region than the subtropical region. This is because of the tropical nature of Indian climate (*see Chapter-4, Climate*), because of influence of the Himalayas which separates the Asian mainland from its temperate influence.

The occurrence of various forest types in the country, as based on the interpretation of Landsat imageries of 1981-83 is given in table 5.2.

Table 5.2: The occurrence of various forest types in the country

FOREST TYPE	AREA (km2)	%AGE	OCCURRENCE
Tropical Wet Evergreen Forest	51,290	8.0	
Tropical Semi-Evergreen Forest	26,424	4.1	Assam, Gujarat, Karnataka, Kerala, Maharashtra, Naga land, Orissa, Tamil Nadu, Andaman &Nicobar Islands and Goa

Himalayan Dry Temperate Forest	312	-	Jammu & Kashmir and Uttar Pradesh
			Arunachal Pradesh
Sub-Alpine and Alpine Forest	18,628	2.9	Jammu & Kashmir, Nagaland, Sikkim and Uttar Pradesh.

Source Forest Survey of India

Mangroves: An Unique Ecosystem

Human beings originated on grasslands or savannas in the tropics where abundant food was available for consumption. Flowering plants also evolved in areas where conditions for their growth were conducive - warm temperature, bright sunshine, high relative humidity and moist soil - in tropical shallow wetlands.

From this stock, trees evolved according to specific stresses in the environment : too high or too low temperature, too much or too little water, and so on. One of these branches of evolution led to plants adapted to high salinity. Most plant species in this branch specialised themselves in avoiding salts in the vicinity, at least in avoiding ill effects of salt stress, and came to be called halophytes.

Some halophytes can also withstand water stress, hence they could grow in arid saline lands. A great majority, however, grow in salty marshy areas along tropical and sub- tropical coastlines - muddy banks of river estuaries, creeks, backwaters, and along sea shores. These are mangroves - Nature's miracle.

There are several adaptations in mangroves that make them absolutely unique. For example, they have glands on leaves through which salts absorbed by the roots are exuded; high concentration of the liquid in their cells (sap) prevents loss of cell turgidity; seedlings grow on parent trees and avoid saline conditions in juvenile stages; pneumatophore roots grow upward and emerge above saline muds to start breathing through microscopic pores in the bark, or roots grow from shoots and reach the soft mud around the main stem to provide stability to trees on the unsteady substratum that are continuously subjected to tidal forces.

Mangroves are a rich ecosystem. The habitat of mangroves is extremely conducive to numerous forms of life thanks to abundance of moisture, nutrients from decaying organic litter, minerals arriving with runoff surface waters like rivers, and abundant sunshine. The shade provided by dense foliage and shelter by profusely branching roots, ensure excellent and secure homes for a large variety of organisms like insects, worms, crabs, prawns and fish, during growth and especially during breeding periods. Parasites and predators (snakes, birds, wild cats and foxes) and saprophytes and predators (worms, insects, molluscs, frogs, birds, etc.) find support in the region.

Another significant contribution of mangrove vegetation is arresting the movement of soft muds with tidal movements of water, thus providing effective control of soil and mineral nutrients from flowing into the seas. A mangrove ecosystem is a unique system. The need for conserving this type is felt intensely.

Programmes have been initiated by the Department of Environment, Government of India, since 1986, to study, conduct research, cultivate and propagate mangroves and to devise practices for the management of mangrove ecosystems.

Mangroves areas are being selected for absolute conservation and mangrove management plans are being prepared. The Sunderbans in West Bengal, Pichhavaram in Tamil Nadu, Kachchh in Gujarat and Andaman and Nicobar islands are already identified for the purpose. Some States like Maharashtra have declared mangrove species as protected by law. Mangrove parks are being designed in Goa and Maharashtra. It is hoped that a concerted and co-ordinated action programme by different authorities responsible for conserving coastal and hill ecosystems will ensure perpetuation of this unique systems of nature's creation.

Sir

The Shola Forest

The term 'shola' has been used in Major Hamilton's Report of the Survey of the Anaimalais in 1854. According to M. Krishnan, shola forest are considered peculiar to southern India and a somewhat distinctive type of tropical rain forest.

Originating millions of years ago, these forest have evolved through geological epochs, which is one of the reasons for the density of species. Varieties of birds and insects act as pollinators and help in the evolution of new species by natural hybridisation. Thus the rain forest is one of the earth's biggest genetic pools. The wild ancestors of many of todays food crops such as rice and barley can still be found in the forests. It is in these forests that the evolutionary history of plants and animals is recorded and it was in one such forest that Darwin got the clues to his theory of the origin of man.

The sholas of southern India are part of the Indo-Malayan forest chain and differ in some respects from other rain forests. They occur amidst stretches of grass lands in isolated patches. They form a characteristic landscape in the mountain chain of the *Anaimalai*, *Palani* and *Nilgiri* ranges. The tree in these sholas are short compared to the other rain forests and range from 12 metres to 20 metres. The crown of the trees is dense with leathery leaves which tend to be rusty in colour in varying degrees when young. The leathery texture of the leaves makes them less vulnerable to insect damage and hence to nutrient loss. The tree trunks are *covered with creepers, lichens and algae.*

The tree species common in the sholas are Kattushenbagam (*Michelia nilgirica*), Pathachi (*Elaesocarpus ferrugineous*) and Mullakadambu (*Mahonia laschenaultii*). The under growth has *Strobilanthes* and *Impatiens* species. On the ground is *a* wealth *of ferns and mosses*. *Orchids*, *both terrestrial* and epiphytic, abound.

The sholas sustain an interesting variety of fauna. The lion - tailed macaque and the Nilgiri langur, the country's only black monkeys, are resident of these sholas. It is also the home of king cobras and green pit vipers. Birds such as the Malabar tragon, the grey headed flycatcher and the great Indian hornbill can be sighted in the sholas. The grasslands are home for the Nilgiri-tahr, the endangered mountain goat.

Just a hundred years ago, sholas covered wide areas of southern India, forming a continuous belt in most of the Western Ghats chain. A Nilgiri langur could have swung its way all the way from Topslip to Kalakkad. But things began to change by the end of the last century. The sholas that remained inviolate for millennia came to be destroyed by man.

Now sholas are confined to isolated patches in places such as Solaiyar and Manjolai in Tamil Nadu, Eravikulam and Silent Valley in Kerala and Agumbe in Karnataka. Some of the most verdant sholas forming a breathtakingly beautiful landscape are in Grasshills near Valparai in Tamil Nadu. This is one of the very few spots where the original ecosystem, the shola-grassland combination, remains intact, not by design but due to the tough weather conditions that prevail there.

Much remains to be studied about the nature of rain forests like the sholas. Its very complexity has deterred closer analysis and this is only one of the reasons why the sholas should be preserved. They are not only part of earth's genetic heritage but a natural and unique heritage of India. Nothing can replace the shola forests, a product of millions of years.

Grasslands of India

Although grasslands of the type of Steppes, Pampas, Veldt, Savannas, Llanos are absent in India, still grasslands in India are found on wet soils and frost packets in the Sal belt and in the hills and other parts of the country. In the lower alluvial deposits, where trees cannot be colonised, extensive grasslands are found. Even in the higher alluvium they have resulted from anthropogenic factors. In general, grasslands represent degenerated vegetation. In areas affected by fire, grazing, felling, etc. The grasslands occurring in India belong to three categories - Hilly and upland grasslands, Lowland grasslands and Riverine grasslands.

1. Hilly and upland grasslands

They are found mostly in the Himalaya above 1,000 m. and on Nilgiri and other hills in South India, where forests have been cleared up.

In the Himalayas, a variety of grasses are found changing their character with altitude. At foothills, tall and coarse grasses like *Saccharum spontaneum, S. venglenese, Arundodonax, Marenga, Porphyrocoma*, etc., are found. Between 2,500 m. and 3,500 m. grasses are found interspersed with the pine, oak and deodar trees. Above 3,500 m., forests give way to grasses which extend up to snowline. A majority of the species found here have close affinity with temperate

climates and in its higher elevation, many species are identical to the same as those occurring in the mountains of Europe and America. High grassy meadows are differently known in different parts; as Margs in Jammu & Kashmir and *Bugiylas or Payas in Uttarakhand. These grasses reach their full bloom in Autumn* just after the rains when majority of grasses flower. These grasslands constitute a very good grazing ground for cattle and sheep during summer.

2. Lowland grasslands

They occur in the plains of Punjab, Haryana, Uttar Pradesh, Bihar, and northwestern parts of Assam where rainfall is high and the climate is of humid tropical type. Both perennial and seasonal grasses occur in these places. The perennial species are *Aristida cyanatha, Dichanthium annulatum, Heteropogon contortus, Dismontachya bifinota, Porokolus indicus, Nerandia arendiances, Eragrostis tremula, E. viscosa, E. tenelia, E. ciliaris, Chenchrus biflorus* and *Aristida redacta*, etc.

3. Riverine grasslands

The most important of the riverine grasses occurring on alluvial, sandy and loamy soils are known as bhabhar pastures. These pastures constitute an important feed for cattle and buffaloes. Important grasses are *Erianthus olivaceus, E. vulpines, E. lensice indica, Paspalwm species*, etc.

Important Words

Epiphytes	**Climbers**	**Llianas**
Halophytes	**Buttressed roots**	**Parkland**
Stilt like roots	**Edaphic**	**Xeropphytic**

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6

SOILS

Introduction

Indian soils, like elsewhere reflect the combination of factors that have gone behind in forming it. The correspondence of the soil forming processes and particularly climate is so perfect that each climate type has its own soil

The broad components in the formation of soils are

(a) The underlying rocks whose breakdown by weathering gives the regolith. This is called the **parent material.**

(b) Landform and its configuration, particularly the slope aspect whether the slope is steep, gentle or undulating. This is of much significance since this will determine whether the soil is going to be thick or thin; prone to accelerated erosion or degeneration, etc.

(c) Climate, the most important factor in soil formation, acts through moisture conditions (precipitation, evaporation and humidity), temperature and wind. These directly affect the formation of soil. Indirectly, climate has an overwhelming influence on the type of vegetation to be found in a particular region. This vegetation is responsible for the colouration and the structure of soil, not to speak of the nutrient which it provides to the soil. Only when these processes have acted for enough amount of time that the soil comes into being. Otherwise it remains immature. None of these factors, however, work in isolation. They all have an

integrated effect and every other component is inseparably linked with every other component making a **soil forming system**.

Formation of Indian Soils

In Indian conditions, there is wide diversity as regards to its geological setting, physiography, climate and vegetation, therefore, it is least surprising that the soils too display wide diversity. The soil forming factors, the parent material, relief, climate, natural vegetation, each are different in different regions.

Parent Material

The parent material of which the soils are formed is derived from the weathering of the rocks exposed on the surface. The parent material determines the colouration of the soil, its mineral composition and texture. In India, the parent material is of diverse types. They can be categorised as

(i) Ancient crystalline and metamorphic rocks

(ii) Cuddapah and Vindhyan rocks

(iii) Gondwana rocks

(iv) Deccan basalts

(v) Tertiary and Mesozoic sedimentary rocks of extra peninsular India

(vi) Recent and sub-recent rocks

The ancient crystalline and metamorphic rocks, which constitute a greater part of the peninsular region, are basically gneiss and schists rich in ferromagnesian materials. These rocks on weathering have given rise to red soils whose red colouration is due to the presence of iron oxide. The Cuddapah and the Himalayan rocks have weathered to give calcareous and argillaceous soils These soils are quite mature.

The Gondwana rocks, in general, have given rise to thin pale calcareous soils rich in humus. The Deccan traps are composed of basalt. Basalts are naturally richer in

titanium, magnetite, aluminium and magnesium. Thus, the weathering of these rocks has given rise to soils darker in colour because they are rich in titaniferous magnetite. The plateau soils have undergone a series of changes in their chemical composition. In general, the plateau soils tend to be coarse grained and less fertile.

The Tertiary and Mesozoic sedimentary rocks of extra peninsular India has given rise to soil with high porosity. The soils found on the North Indian plain do not bear any relationship with the parent material as they are transported and reworked soils

Relief

Landform configuration (relief) affects soil in that it determines the degree of runoff, susceptibility to erosion and consequently thickness or thinness of the soil. Where the slope is steep, high runoff will lead to washing of the top layer and the soil tends to be thin with little development of profile. This happens in the Himalayan regions where the slope is steep. The same is the case with the plateau soils where the soil is shallow except river valleys. In very flat regions, where drainage facility is poor and water logging is the rule, the soil tends to be peat and accumulate large amount of organic material.

Climate

It has already been noted what an important part climate plays in soil formation. In areas of high rainfall and humidity where the temperatures are also high the soils are red or lateritic. The intense rainfall during the rainy season washes the upper soil and leaches the nutrients into the deeper horizon. With the coming summer, the evaporation exceeds precipitation and through capillary action iron and aluminum sesquioxides are transported to the surface making the soil red. Also, under such hot humid conditions, where vegetation is thick and luxuriant the soil should supposedly be containing enough humus, but the soils are devoid of any humus content In areas of alternate wet and dry climate, the leached material which goes deep down in the horizon is brought up in the blazing sun bakes the top soil so hard that it resembles a brick, hence the name laterite. In such areas where evaporation always exceeds precipitation there are two necessary factors that determine the nature and properties of soils First the land, which in the name of vegetation contains only a few shrubs there is little to add to the soil in the name of humus, as a result the soils formed under such conditions are always light in colour. Secondly, the excess of evaporation which

makes these soils lime accumulating. Thus they are bound to be pedocal in nature. This is exactly the case of soils found in the extreme western part of the country. Cold climates, although it may be supportive of some vegetation but under such cold conditions the vegetation decays very slowly so that the soil formed is always acidic in nature The soil found in the Himalayan regions are of such type.

Vegetation

The role of vegetation basically lie in giving humus to the soil. Humus in turn is to a large extent responsible for fertility in the soil and its colouration. The dense vegetation in some parts of our country contain the best soils. The light colouration and low humus content of arid soils in Rajasthan is explained by very thin vegetation cover. In general, Indian soils are quite low in organic contents.

Classification of Indian Soils

Soils vary widely in their characteristics and properties. In order to establish interrelationship between their characteristics, they need to be classified. The understanding of soil properties is important as it can then be put to optimum use and best management requirements for their efficient and productive use. Classification not only reduces the study of the number of individuals to a few well defined units, it also helps to group together such soils which have common and comparable characteristics. To classify soils and group them together in a meaningful manner different soil classification schemes have been used from time to time. One scheme of classification is based on the horizon development and its relationship to climatic conditions (Fig 6 1), and the other - the modern system of classification "Soil taxonomy" developed by the USDA in the seventh approximation (Fig 6.2). The USDA system of classification has been recommended for adaption in India as a result of decision taken at the All India Workshop held in 1969.

The Zonal Soil Classification

Alluvial Soil

The Alluvial soils include the deltaic alluvium, calcareous alluvial soils, coastal alluvium and coastal sands. The alluvial soils are found on 24 per cent of the total land

surface of India. It is found in parts of Rajasthan, Punjab, Uttar Pradesh, Bihar, West Bengal, Orissa, Assam, the valleys of Narmada, Tapti, Mahanadi, Godavari, Krishna, Kaveri, Brahmaputra and Soorma

The main features of the soil are derived from the deposition laid by numerous tributaries of the Indus, the Ganges and the Brahmaputra systems. These streams draining the Himalayas brought with them the weathered products of rocks constituting the mountains in various degrees of fineness and deposited them while traversing the plains.

Characteristics

1. The colouration is generally grey, light brown or yellowish.

2. The composition ranges from shale, loamy, silty to clayey

3. Their textures are variable ranging from very coarse to fine. Generally speaking, the finer the texture of the alluvium the better the soil conditions for plant growth.

4. The profile development varies from underdeveloped profiles to very well developed profiles. In general, however, the profile is not fully developed and there is no marked differentiation and stratification.

5. These soils are largely reworked soils so that the mineral matter is thoroughly mixed up. It is therefore quite rich in chemical and mineral matter.

6. Alluvial soils are inherently rich in plant nutrients. In general, they are fairly sufficient in phosphorus and well supplied with potassium, but are deficient in nitrogen and organic matter content.

However, there are wide spatial variations in these characteristics. For example, the soils of Assam are more acid, the soils of the Brahmaputra are high in potash content, the soils of the Soorma valley are fine textured. The soils of the Rurh region commonly composed of old alluvium are of diverse type in terms of texture, colour, profile, composition and other mechanical properties.

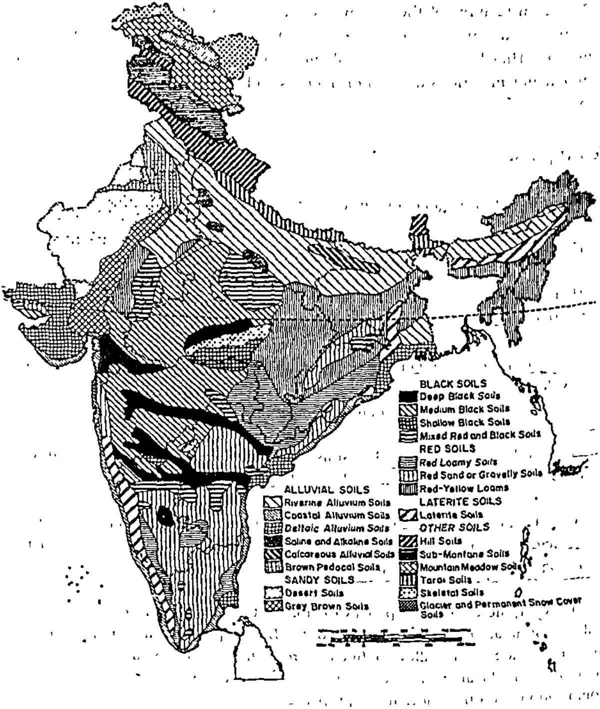

Fig.6.1. The zonal classification of Indian soils

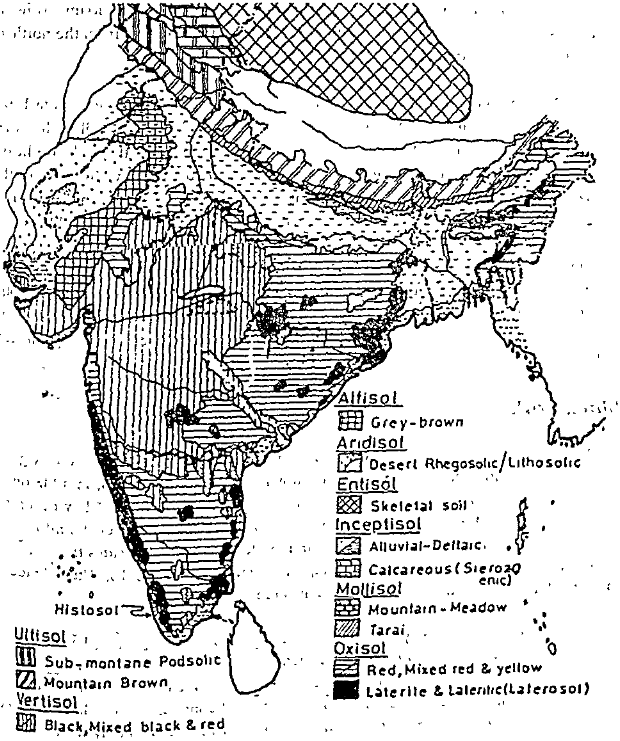

Fig.6.2. The 7th Approximation classification of Indian soils

The alluvial soils of Bihar are different in the north of the Ganges to that of the south of the Ganges The northern alluvium are sandy loam to clayey loam and neutral to alkaline They are relatively rich in potash and deficient in phosphorus. The soils of southern alluvium vary in their colour and texture from light greyish loams to heavy black clays Likewise, the soils of Uttar Pradesh differ in their texture from the northern part to that of the southern part

The Orissan soils are both sandy and of finer texture with sufficient potash but insufficient in potassium (P_2O_5). The composition of alluvial soils of Tamil Nadu varies with the nature of silt brought by the rivers. Away from the rivers the soils are heavy throughout the texture and ranges from clayey loam to heavy clay. In Gujarat, the alluvial soils are known as goradu in Ahmedabad and Kaira district. The older alluvium in Baroda is locally called gorat while the recent depositions are known as bhata.

The Punjab-Haryana alluvial soils are akin to soils of the Indo-Gangetic plain. The majority of soils are loams or sandy loams consisting of soil crust of varying depth Owing to the presence of sodium in the clay the soils are generally alkaline. They are adequately supplied with phosphorus and potash but are deficient in organic matter and nitrogen.

Black Soils

The Black soils are so called because of their black colouration. They are very good for cotton cultivation hence they are also known as Black cotton soils, in addition to their local nomenclature was Deccan plateau composed of lava flows. They cover the plateau of Maharashtra, Saurashtra, Malwa and southern Madhya Pradesh and extend eastward in the south along the Godavari and the Krishna valley. Besides they are also found in north Karnataka, parts of Rajasthan (Bundi and Tonk), Uttar Pradesh (Bundelkhand) and central and south Tamil Nadu.

It is derived from two types of rocks, the Deccan and the Raj Mahal trap, i.e., volcanic rocks, such as basalt and other metamorphic rocks, and ferruginous gneiss and schists containing lime and soda lime feldspar - which are basic in character, occurring in Tamil Nadu state under arid and semi arid condition. The soils developed on gneiss and schists are moderately shallow (50-80 cm) to moderately deep (80-120 cm) while those developed on basalt are very deep (150 cm). They have uniform colour throughout the depth of 2-3 metres.

Characteristics

1. Black soils as the name suggests are deep black to chestnut in colour. The deep black to chestnut colour of the soils is largely due to clay-humus complexes and/or presence of titaniferous magnetite and not due to organic matter content which is low (0.5 per cent to 1.0 per cent).

2. Besides, these also contain compounds of Fe and Al, accumulated humus and colloids, hydrated double iron and aluminium silicate.

3. Black soils mostly have a higher degree of fertility, but soils that are found on uplands are rather poor. On the slopes and uplands, the soils are somewhat sandy and are only moderately productive Between the hills and the plains, they are darker, deeper and richer and are constantly enriched by the additions that are washed down from the hills.

4. The Black soils are made extremely fine, i.e., clayey material particularly montmorillonitic and beidelletic group of clay mineral thus they are highly argillaceous, fine grained and dark. The clay is dominantly sonectic in nature with high coefficient of expansion and contraction setting up a steady churning process within the pedon. The process of churning causes deep and wide cracks.

5. Besides, they also contain high proportion of calcium and magnesium carbonates.

6. The capacity to hold moisture in the black soils is very high. Yet water is not available to plants because of their fine texture.

7. They are highly tenacious of moisture and are exceedingly sticky when wet and consequently have low permeability When they dry up they develop deep wide cracks due to contraction. The cracks promote self aeration and absorption of nitrogen from the atmosphere.

Black soils are rich in potash, lime, aluminium, calcium and to magnesium carbonate, while they are deficient in nitrogen phosphoric acid and organic matter.

In all black soil, in general, and those derived from ferromagnesium schists in particular, there is a layer generally rich in kankar nodules, formed by the

segregation of calcium carbonate at some depth below the surface and above the parent rock

Regionally, the soils differ, for example, in Maharashtra the soils are light coloured, thin and poor on upland and slopes while in the valleys deep and relatively clayey black Along the Ghats, the soils are very coarse and gravelly. Degraded solonised black soils, locally called *chopan*, occur in canal zone areas of the Deccan in Maharashtra. In Tamil Nadu the black soils are either deep or shallow and may or may not contain gypsum in their profiles.

In Madhya Pradesh, two distinct kinds of black soils are found (i) deep heavy black soils in the Narmada Valley (ii) shallow black soils in other areas. The cotton growing areas are on deep heavy black soils.

The black soils of Karnataka are fine textured with varying salt concentration.

Red Soil

The red soils comprise large parts of Tamil Nadu, Karnataka, Goa, Daman and Diu, south eastern Maharashtra and eastern Andhra Pradesh, Madhya Pradesh, Orissa and Chhotanagpur. In the north, it includes a greater part of Santhal Parganas in Bihar, the Birbhum district of West Bengal, the Mirzapur, Hansi and Hamidpur districts of Uttar Pradesh, Assam, Khasi, Jaintia and Garo hills and the Aravallis. They practically encircle the Black soils on all sides.

These deep or very deep well drained soils, with clay enriched subsoil have developed mostly in situ from granite, gneisses and schists of Archaean period under subtropical climatic conditions (with high humidity and temperature conditions). Occasionally the red soils are developed on micaceous schists, sandstone and shales. The micaceous or red granites in Tamil Nadu also gives rise to such soils. The soils grade from poor, thin, gravelly and light coloured soils of the uplands to the much more fertile, deep dark soils of the plains and valleys.

Morphologically, the Red soils can be divided into two broad subgroups:

Red loam: Characterised by argillaceous, clay enriched profile with a cloudy structure and the presence of only a few concretionary material; and

Red earth: where the top soil is loose and friable best rich in secondary concretions as a consequence of sesquioxide type of clay.

Characteristics

1. The colour is red to yellow. This is due to coatings of ferric oxides on the soil particles, rather than due to a high proportion of the iron content. The colour is red when the ferric oxide occurs as haematite or anhydrous FeO, and yellow when ferric oxide occurs in the hydrated form; e.g., limonite.

2. The texture of these soils is highly variable from loamy sand to heavy clay, but generally the red soils are loam to clay loam in texture.

3. The soil depth varies from shallow to very deep. Shallow thin gravelly soil being found on uplands while deep fertile and fine textured soils are found in the valleys and plains.

4. Red soils are poorer in nitrogen, phosphorus and humus and are generally poorer in lime, potash, iron oxide and phosphorus than in regur soils. The clay fraction of the red soils is such in kaolinite type of mineral. Red soils have also been found under forest vegetation. Some red soils are of lateritic origin and of a quite different nature.

The red soils of Tamil Nadu are in situ formations derived from micaceous or red granites. The soils are shallow, open textured, acidic, deficient in organic matter and plant nutrients. The soils of Chhotanagpur region are acidic and also contain a higher percentage of acid soluble Fe_2O_3 than that of Al_2O_3. The West Bengal red soils are the transported soils from the hills of the Chhotanagpur plateau.

Laterites and Lateritic Soils

Laterite is a formation that is found only in tropical countries with alternate wet and dry climatic conditions. It is a compact to vesicular rock composed essentially of a mixture of the hydrated oxides of aluminium and iron with small amounts of manganese oxides, titania, etc.

Laterites are especially well developed on the summits of the hills of Karnataka; Kerala, Madhya Pradesh, the Eastern Ghat regions of Orissa, Maharashtra, West Bengal, Tamil Nadu and Assam In all these places an alternate wet and dry type of climatic condition is found

During rainy season there is extensive leaching of bases and silica, while during prolonged dry season iron and aluminium are brought to the surface by capillary action which are then baked by the blazing sun, compacted and cemented forming a brick like layer They are thus *in situ* in formation.

The laterite may be broken off and then carried to the lower level by the action of streams and then redeposited in lower levels. It may become cemented again into a compact mass by the segregative action of the hydrated oxides including sand grains of quartz and other mineral. There are thus, **high level laterites** which rest on the rocks which led to their formation, and **low level laterites** which are derived and redeposited from high level Therefore they are of sedimentary formations. All lateritic soils are very poor in lime and magnesia and are deficient in nitrogen. Occasionally P_2O_5 may be high being present in the form of iron phosphate, but potash K_2O_5 is deficient. Laterites are characterised by high acidity. There is a general relationship between altitude an the characteristic of the soil, for example,

(i) they are more acidic on higher areas,

(ii) they are poor on higher level and cannot retain moisture,

(iii) on plains they consist of heavy loam and clays and can easily retain moisture.

Laterites are essentially devoid of humus and occasionally a higher content of humus is found.

Arid and Desert Soils

The arid and the desert soils are found in the arid and semi arid conditions in north western parts of the country belonging to western Rajasthan, southern Haryana and south-west Punjab, lying between the Indus River and the Aravalli hills covering an area of 29 million hectares.

Characteristics

1. The soils are fine sandy to loamy, fine sand in texture with percentage of clay varying from 3.5 to 10 0.
2. They are pale brown to yellowish-brown in colour, and structureless to weak subangular blocky in structure.
3. They are generally poor in nutrient and water-holding capacity.
4. They have the tendency to disperse on account of sodium-clay formations in the subsoils which may render them less permeable and may retain more moisture.
5. Where moisture is not deficient, the presence of phosphates together with nitrates goes a long way to make these desert sands fertile for growing selected crops.
6. The pH of these soils varies from 7.2 to 9.2; generally between 8 1 to 8.6 because of their calcareous nature.
7. The salts are generally high but are not toxic in amount.

Saline and Alkaline Soils

Saline and alkaline soils are found in the arid and semi arid parts of Rajasthan, the Punjab and Haryana. They are estimated to occupy 7 mha of which about 50 per cent are in the Indo-Gangetic Plain, 30 per cent occur among Black Cotton soils and the remaining 20 per cent are in arid and coastal regions of India. There are three classes of saline and alkaline soils.

Saline soils

These contain toxic concentration of soluble salts mainly consisting of chlorides and sulphates of sodium, calcium and magnesium. Because of the white encrustation due to salts, the saline soil is also called **white alkali**.

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Non Alkaline or Sodic soils

These soils do not contain any large amount of neutral salts but have a high percentage of sodium carbonate. The results in high alkalinity and consequently the surface soil is discoloured and black and hence the term black alkali is frequently used to designate the non saline alkali soils.

Saline Alkali soils

They are both saline and alkaline and have appreciable amount of salt. The various local names of the three classes of saline soils are

Saline.	*Thur, Shora, khar, Kari, Lona, Pokkati, Soulu*
Saline Sodic:	*Ushar, Mallar, Karl, Chopan, Rih, Kshar, Bari*
Sodic:	*Rakkar, Bara, Usar, Karl Chapan*

Mountain and Forest Soils

The mountain and forest soils are distributed along the Himalayan and the Satpura ranges, Nilgiri and Cardamom hills They are thus found in the states of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Nagaland, Assam, Meghalaya, Orissa, Arunachal Pradesh, Madhya Pradesh, Mizoram and Manipur along the Himalayan mountain region. The characteristics of these soils differ from region to region depending on the climate but vegetation and topography also control the soil profile development. These are characterised by high amount of organic matter content due to deposition of organic matter from forest growth but the slow decomposition of humus causes acidic conditions. The major soils, as observed in different forest areas are: Brown Forest and Podzolic (in the Deccan plateau)

Podzolic Soils

Those soils formed under coniferous vegetation in the presence of acidic humus and low base-status are Podzolic in nature. Owing to leaching of bases and translocation of sesquioxides, the soils developed under coniferous vegetation (especially Deodar)

do show podzolic characteristics. The process of podzolisation, as operative in the Himalayas is restricted to the mobilisation of sesquioxides.

Characteristics

The podzolic soils are characterised by

1. Moderate (to strong) acidity with pH varying from 5.0 to 6.0.

2. High organic matter (2-3.5 per cent), and moderately high (20-30 per cent) clay content.

3 Deficiency in phosphorus resulting from the formation of iron and aluminium phosphates.

Brown Forest Soils

The other soil formed in the forest areas developed on sndstone, limestone or colluvium, under subhumid (to humid) climatic environments and Pinus and/or mixed vegetation are Brown Forest Soils. These soils occur in association with podzolic group of soils.

The soils have:

(i) neutral to slightly acidic reaction with pH generally varying from 6 to 7; the soils developed on calcareous sand stones. However, show pH up to 8.0.

(ii) moderate to high accumulation of humus at their surfaces with organic matter content varying from 1 to 3 per cent.

(iii) high biological activity.

Peaty and Organic Soils

Peaty and organic soils develop in hot humid conditions as a result of accumulation of large amount of organic matter. It is essentially found in Kerala (where they are

submerged under water in monsoons and are known as *kari*), North Bihar, coastal parts of Orissa, West Bengal and Tamil Nadu.

Characteristics

Peaty or Organic soils

(i) are dark and almost black in colour with abundant (20-40 per cent) organic matter content

(ii) are fine in soil texture.

(iii) show the accumulation in moderate amount of ferrous and aluminium sulphates, iron pyrite in these tidal swamp areas When drained, the pyrite (FeS_2) is oxidised and sulphuric acid is formed, resulting in pH values below 3.5 or 4.0.

(iv) are very strongly acidic with pH as low as 3 5 to 4.0. They may also be due to the decomposition of organic matter under anaerobic conditions where no nitrification is possible.

The Marshy Soils are confined to depressions caused by dried lakes in alluvial and coastal plain areas. They are developed under anaerobic water logged environments, which result in the formation of bluish/greyish coloured soils. This may be due to the presence of ferrous iron and varying amounts of organic matter.

USDA 7th Approximation Classification

Till here

The equivalents of these in the soil taxonomy groups are:

Alluvial soil	Entisol, Inceptisol, Alfisol.
Black soil	Vertisol, Inceptisol.
Red soil	Entisol, Alfisol, Inceptisol.
Laterite soil	Vertisol, Alfisol, Ultisol.

Desert soil Oxisol, Entisol, Aridosol.

1. Inceptisols

Inceptisols (Latin: '*Inceptum*'- beginning) are found in the vast Indo-Gangetic plains extending from Pakistan to Assam and embracing the riparine and deltaic region of Bengal and the floodplains of the Mahanadi, Godavari, Krishna, Kaveri, Tapti, Narmada, Sabarmati and many rivers of Kerala.

Inceptisols are characterised by light colouration, loamy texture and drier composition. Inceptisols are basically reworked soils and exhibit very little pedogenic variation. These soils are usually not dry and have one or more of the diagnostic horizons (cambic, umbric, or mollic with low base saturation). They have developed rather recently owing to the alteration of the parent material but without much leaching and accumulation of material in the subsoil. The horizon is not fully developed and the thickness varies from place to place. The inceptisols may be acidic (pH 5.5) or calcareous (where the content of the bases varies from 40 to 70 per cent or even alkaline) resulting from human activity.

2. Vertisols

The Vertisols are associated with the Deccan and the Malwa plateau of western and central India. These vertisols are built up of basaltic lavas and pyroclasts, and are highly argillaceous black and loamy soil containing carbonates of Ca and Mg, Al_2O_3, iron oxides, small amount of potash, soda and traces of phosphates, all of which are responsible for imparting fertility to the soil. The vertisols have a high amount of swelling montmorrilonite clays (>30 per cent) so that it is highly retentive of moisture and is quite sticky when wet but at the same time as the soil dries out it develops deep cracks (5-10 cms. deep) which provides self aeration to the soil and intake of nitrogen from the atmosphere.

Marginally, this soil grades into red soils (Alfisols).

3. Alfisols

Alfisols are found on the margins of Vertisols. Unless sodium enriched, these soils tend to develop under varied types of climate (subhumid to humid of temperate and

tropics) and forest vegetation. The removal of flocculation agents like Ca-Mg carbonates and bicarbonates, is a prerequisite for the movement of clay under the influence of percolating water They are characterised by medium to high base content and a subsurface clay horizon usually moist but which dry during warmer season. Because of the high base saturation, favourable textures and locations in subhumid and humid regions, the Alfisols are quite productive and suitable for good crop yields. In Punjab, they are used for growing crops, sodium rich alfisols need ameliorative measures using gypsum as an amendment before bringing them under the plough.

4. Oxisols

The oxisols (French: '*oxidi*'-oxide) are found over large tracts of the peninsula where the climate is hot and humid and have rather uniform temperature conditions It has a residual accumulation of inactive clay predominantly (50-80 per cent) kaolinite with oxides of Si, Fe, Al. Weathering and intense leaching are responsible for the removal of a large part of silica from silicate minerals leaving behind a high proportion of the oxides of iron and aluminium. The clay content of these soils is very high: but unlike in vertisols it is non-sticky and 1:1 type (**kaolinite**). The surface horizon of granular to subgranular material is dark red brown or yellowish red. The profile is deep but there is little differentiation.

The deeply ferruginous oxisol known as laterosol is usually 60 to 90 cms. in thickness and is capping on plateaus, low hills and undulating terrain in areas of high rainfall. The oxisols having dominantly kaolinite clay and abundant sesquioxides are also called ***nitosol*** Laterosols are deficient in natural nutrient such as magnesia, lime phosphates and nitrogen compounds but have some good physical properties such as granularity and permeability.

5. Histosols

Histosols (Greek: '*Histos*'- tissue) are found in the water saturated environment, marshy tracts of delta of Ganga, Godavari, Krishna, Pennar, Kaveri and rivers of northern Kerala between Cochin and Allepey along with the northern border of Indo- Gangetic plain in the foothills of Kumaon and Nepal Himalayas. Histosols contain abundant amount of organic matters such as woody pest and decomposed muck.

6. Ultisols

Ultisols (Latin: '*Ultimum*'-last) are found in the Himalayan submontane region. These are low base status, timbered mineral soils of humid region developed under high rainfall and forest vegetation. They are characterised by low (<35%) base saturation, and accumulation of clay in the subsoil. In the pedogenic evolution, they represent an advance stage of weathering and are more acidic than the alfisols, but not as acidic as the Spodosols.

Extensively leaching and warm temperatures favour the alteration of primary weatherable minerals into secondary clay minerals and oxides (especially of iron) which imparts red or yellow colours to the subsurface horizons showing high chromas. They are ash grey to pale yellowish brown and are characterised by deficiency in bases, colloids and oxides of iron and aluminium (due to leaching. Because of low fertility and low base status, these soils pose limitations for agricultural use. They can support only larger coniferous plants such as pines, deodars, spruce, cyprus, etc., and agricultural crops only when they are adequately limed and fertilized.

7. Podsols

Podsols develop on carbonate rocks such as limestone and dolomite of Vaishnodevi of Jammu, Shale of Himachal Pradesh, Deoban of Garhwal, Kumaon and Himalaya. These are characterised by large amounts of Ca, Mg, P, Mn, organic and nitrogenous matter besides Fe, Al and K. They largely support temperate forests.

8. Mollisols

Mollisols (Latin: '*Mollis*'-soft) are found at higher altitude having youthful landscape. They have developed on lime-rich parent material in which there has been decomposition and accumulation of large amounts of organic matter. They are distributed in subhumid to semi arid regions where leaching of bases is low and moisture sufficient enough for addition of organic matter. The topsoil is thick, dark and rich in humus dominated by bivalent cations. The underlying horizon is either altered rock material or clay which are calcic or sodic depending upon the parent rocks underneath. Mollisols are characterised by dark-coloured thick organic matter rich surface horizon. They have high base saturation with abundant calcium. Their

characteristic feature result from the decay of organic material producing some stable dark compounds and reworking the soil and organic matter by earthworms.

These soils are predominantly observed in the Terai region of Uttar Pradesh and in some parts (Kulu region) of Himachal Pradesh. These soils produce optimum yields both under irrigated and unirrigated conditions without inputs.

9. Entisols

Entisols are found in the cold deserts of northern Laddakh and adjacent Tibet. They have thin covers of skeletol soil and are characterised by absence of pedogenic horizon and great variation in texture, colour and composition.

10. Aridosols

Aridosols (Latin: '*Aridus*'-Dry) are mineral soils of dry places (arid and semi arid regions) and of areas having high ground water table. The soils remain dry for most part of the year and the salts accumulate at the surface and/or in the solum resulting in the development of a salic, gypsic or calcic horizon.

These soils were formerly designated as Desert, Reddish Desert, Sierozem. Reddish Brown and Solonchak. The Aridosols orchids are widely distributed in south western parts of Haryana and Punjab and in localised pockets in the central Punjab. Without irrigation these may not be suitable for growing crops. However, in Haryana and Punjab, they are used for growing one crop a year by following water conservation practices

11. Spodosols

Spodosols (Greek: '*Spodos*'-Wood ash) are mineral soils with accumulation of humus and sesquioxides in the subsoil. They are characterised by a bleached, wood ash-coloured E horizon (considered diagnostic of Podzol) and an illuvial Bh and Bs horizons which contain humus and free sesquioxides (considered diagnostic of Spodosols).

The *soils develop on coarse textured (sandy) parent material supporting* acid producing vegetation, like coniferous and heath under cold and temperate climatic conditions.

Spodosols are not fertile soils and are used for forestry and/or pasture. When fertilized, they may be used for growing crops.

In India, true Spodosols/Podzols are seldom found because of the lack of typical parent material and/or environmental conditions needed.

Soil Degradation in India

To do till end. Sir

Degradation of the soils is the most important problem of the Indian soil. Degradation refers to a variety of factors which leads to the overall loss of the quality of the soil. Degradation includes laterisation, alkalisation and salinisation of the soil *and soil erosion, i.e., the loss of top soil. Soil degradation results from a combination* of natural and anthropogenic factors. While the natural forces have been always acting on the soil to cause slight degree of degradation it has greatly intensified of late on account of human impact.

Soil Erosion

Soil erosion is the wearing away of land surface by the action of such natural agencies as water and wind.

Factors affecting Soil Erosion

Soil erosion is greatly influenced by

1. Precipitation (its intensity and amount)

2. *The slope of land (its degree and length)*

3. The type of soil

4. The nature of ground cover and landuse

1. Precipitation

The intensity of rainfall its duration and frequency influence the rate and volume of runoff A light rain is easily absorbed in the soil and causes no runoff and soil loss. Rainfall of long duration and greater frequency increases both the total runoff and soil loss. Apart from intensity and duration of rainfall, the amount of soil moisture is an important variable. If the soil is already saturated with moisture the same amount and intensity of rainfall will cause more runoff and soil loss than from a dry soil.

In India, most of the precipitation is [illegible] of the annual rainfall of the country is rece[illegible] The monsoonal rainfall which comes in torre[illegible] oil erosion in the country. Areas which receive higher rainfall and has steep slopes are more vulnerable These include north eastern India, Western Ghat region, Chhotanagpur region, etc.

2 Degree and Length of slope

The speed and the extent of runoff depends on the slope of the land. The greater the slope, the greater is the velocity of the flow of the runoff. If the velocity of the runoff water is doubled, its erosive power is increased four times and the quantity of the material of a given size that can be carried is increased 32 times. In any case the rate of erosion increases rapidly.

3. The type of soil

The type of soil, i.e , its structure, texture, organic matter content, its infiltration capacity and permeability greatly affects the soil loss and runoff. Fine soils are more prone to erosion than coarse soils.

Lateritic clays are less erodable than black soils which are moderately to highly erodable. In arid and semi arid areas moist soils are less prone to deflation than dry soils.

4. The nature of ground cover and landuse

When rainwater falls on a surface covered by vegetation, two things happen

(a) the falling water is intercepted and it slows down.

(b) the water quickly percolates through the soil or moves over the surface without any erosive velocity.

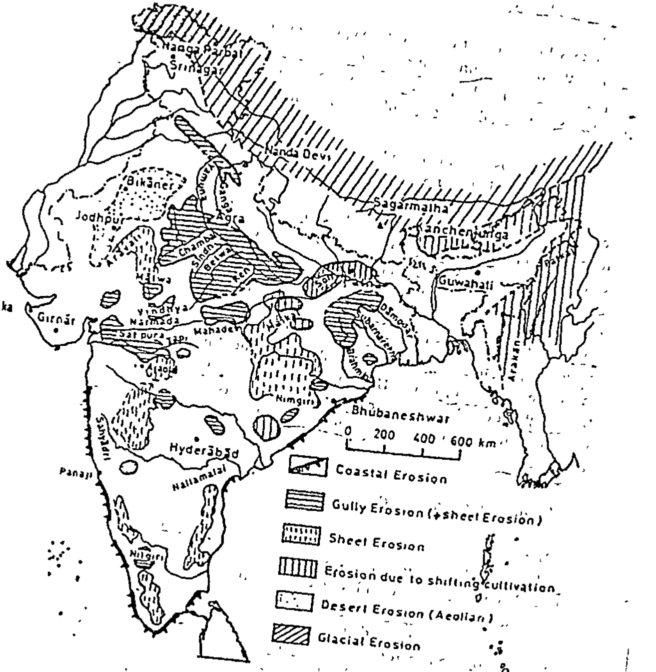
Areas which are not covered by vegetation are unable to absorb water effectively because the beating rains shatter the exposed soil surface, the fine soil particles go into suspension and the thick mixture of water and soils quickly fills and closes the tiny interstices in the soil reducing infiltration. Thus, the runoff and soil loss, increases.

Vegetation losses which has been brought about by indiscriminate deforestation to meet certain needs like timber, fuelwood, project construction, etc had a disastrous effect on the soils Once the vegetation is lost, not only the binding factor of soil gets lost but also the soil is exposed to beating rains. Moreover, tree crowns control and resist the velocity of winds and thereby protect the earth from wind erosion. The disturbing consequences of deforestation and destruction of plant cover is very much evident in the Siwalik hills in Hoshiarpur district, which has increased the extent of degraded lands by 10 times. Overgrazing of pastures by animals strips of the protective cover and exposes soils to a devastating degree of erosion. Sheep and goat are particularly a menace in Himachal Pradesh, and hilly areas of Uttar Pradesh. The incidence of grazing in the Himalayan district of Kumaon and Garhwal is 2.5 to 4.5 times higher than the carrying capacity of the forests. Additionally, pounding of hooves of cattle lead to formation of cattle tracks which later develop into gullies and thus initiate erosion.

5. Agricultural Practices

Unscientific agrucultural practices that cause reduction in permeability and roughness of the soil invariably lead to greater erosion. This is because the shallow topsoil becomes saturated with water in a shorter period so that surface runoff develops sooner than it would, if the soil were thicker. Soils which are shallow are more prone to erosion especially if the degree of slope is higher. In general, agricultural [illegible] on steep slopes are wrong practices and more so on convex slopes. There[illegible] agricultural practice that breaks the slope and forms convex slope esca[illegible] of erosion. In the mountains, making plough furrows in the direction of the [illegible] provision of drainage ditches, greatly accelerates erosion. This is very [illegible] large parts of Garhwal, Kumaon and Nepal.

Fig.6.3. Forms of soil erosion in India



Forms of Soil Erosion

1. Normal or geological erosion

This is a normal feature of any landscape. Geological erosion takes place steadily but slowly that an enormous time is required for it to make any marked alteration in the major feature of the earth's surface. There is always an equilibrium between the removal and formation of soil. This equilibrium may get disturbed by some outside agency and when this happens there is more soil loss than can be replenished.

2. Accelerated Soil Erosion

The removal of the surface soil from areas denuded of their natural protective cover consequent upon human and animal interference is termed as accelerated soil erosion. Accelerated soil erosion takes place at a faster pace than the soil is formed It takes about 1,000 years to build the top 2.5 cm. of the soil but it only takes one or two year for this soil to get eroded.

3. Wind Erosion

Wind erosion involves carrying away of finer particles of soil. It depends largely on wind velocity, the amount of vegetation cover and moisture content in the soil. Wind acts selectively in winnowing away the particles of dust. Wind erosion is doubly damaging as at one place it depletes the land of its top soil and at another it burries the crop under the heap of sand. Wind erosion is maximum during dust storms. About 38 7 m.ha. of the Indian soils is affected by wind erosion, particularly, *in Rajasthan and Gujarat region where wind erosion is aided by climatic conditions* and absence of vegetation.

4. Water Erosion

Water erosion has many forms such as

(a) **Rain erosion**- The falling raindrops possess considerable kinetic energy. With this energy they loosen the soil and initiate erosion by dispersing its aggregates and splashing them around In the absence of intercepting trees, shrubs and

grasses the raindrop erosion assumes serious proportion as billions and billions of raindrops pound the soil surface and splash the particles downslope. This type of erosion is most pronounced where tree canopies have vanished, in agricultural fields which are without crops and on road cuttings. In India, it is happening in Kerala, where plantations of cardamom have replaced the original tropical rain forest vegetation cover, offers less resistence against beating rains, exposing the top soil. A similar phenomenon consequent upon loss of canopy cover is taking place in North Eastern region, Chhotanagpur and almost everywhere.

(b) **Sheet erosion**- When the rainfall becomes very heavy and the soil has lost the capacity to absorb water, the rainwater accumulates and then flows down in irregular manner carrying a thin film of soil with it. The intensity of sheet erosion depends on the steepness of the slope and on the volume of the flowing water. Sheet erosion denudes the soil almost uniformly making it thinner, although the loss is imperceptible.

(c) **Rill erosion**- Sometimes the flow gets concentrated in thin thread like channels forming grooves called rills. Year after year, rills slowly increase not only the numbers but also in their shape and size. This type of rill erosion is particularly prevalent in the *Chhos* region of Punjab.

(d) **Gully erosion**- Gully erosion is the developed stage of rill erosion. When rill erosion goes unhindered then the rills get deepened and widened every year and are enlarged to form gullies. The gullies vary in width and depth from tens of centimetres to couples of metres. They further get deepened and widened with every rainfall. They may be continuous, evolving on the ground surface as a result of concentration of overland flow. They may also be discontinuous and particularly associated with subtraction concentration of flow in soil pipes caused by local lowering of water table. If rejuvenation has taken place they may be trenched.

Gully erosion is the result of many factors which include

(i) the gently sloping nature of the land,

(ii) the loamy sand, the sandy loam and the silty loam texture of the soil,

(iii) intense rain in the monsoon,

(iv) improper landuse by resorting overgrazing,

(v) the biotic interference with the natural vegetative cover, and

(vi) faulty agricultural practices.

At an advanced stage, gully erosion has given rise to gorges and canyons and merging of gullies have led to the development of badland or ravinelands. The best example of badland type of topography is an exhibition by Chambal ravineland in north eastern Madhya Pradesh and adjoining Rajasthan. Other places which have developed characteristic of ravinelands are the valleys of Sabarmati, Mahi and Vatrak in Gujarat and catchments of the mayurakshi, the Kangasabati and the Gomti.

(e) **Strip erosion-** Strip erosion is usually caused by hydraulic pressure exerted by moisture penetrating the soil during heavy rains. Due to low permeability of soil, the rain could percolate quite deep below the strata. Thus, a great mass of overlying soil on steep land comes down bodily.

(f) **Streambank Erosion-** Streambank erosion is acomplished by short hill streams or torrents which have flashy flows, swift current, ill defined banks and have wide spreading beds after emerging from hills. These streams get swollen up during rainy season and carry huge amount of detritus of comprising boulders, shingle, sand and silt depending upon the geology of the terrain. The detritus material gets deposited as the stream emerges from the mountain.This raises the channel of the stream. The large amount of debris reduces the transporting capacity of the torrent resulting in overflows, meandering of the stream and bank erosion.

(g) **Coastal Erosion-** Coastal erosion is another form of erosion caused on the sea coast by constant pounding of waves and currents. Coastal erosion is quite pronounced during storms and cyclones when the waves and currents both are very strong. Coastal erosion is most pronounced along the western and eastern coast and especially on the coasts of Orissa, Bengal and Kerala. The shortage of sediment supply in the longshore drift caused by the entrapment of riverine sediment in the waves, thus increases the erosive capacity of the waves.

This is the principal reason behind coastal erosion.

The intensity of the soil erosion depends on both volume and velocity of water and there is a fourfold increase in the eroding ability when the velocity doubles (the carrying capacity increases eight times). The kinetic energy in channels may rise up to 2,500 times greater than the kinetic energy of the sheet runoff. This is why, the intensity of erosion is greatest in gullies and ravines. The universal soil loss equation provides a measure of intensity of erosion - the amount of soil removed from its original position

E = RKLSCP

Where,

E = Soil loss

R = Rainfall erosivity index

K = Soil erodibility index

L = Length of slope factor

S = Steepness of slope factor

C = Cropping and management factor

P = *Conservation practices factor*

Soil Erosion in India

Soil loss in India is assuming alarming proportions. Part of the problem is largely because we have about 43 per cent of the land under cultivation and our population is increasing at a very fast speed. Soil loss leads to the loss of nutrients and in this way it is of the order of 5 37 million tonnes of NPK valued at 700 crores. Every year in India water erosion alone takes away more than 6,000 tonnes of top soil containing more than 1,000 crores worth of nutrients. The erosion causes rapid siltation of tanks, and reservoirs and rivers themselves. This has many effects -While the raising of the river channel is responsible for flooding in the lower reaches at the same time it has reduced the effective life span of dams. The land area prone to floods has doubled from 20 million hectares in 1971 to 45 million hectares in 1990. The Bhakhra, Maithon, Panchet, Konar and many other dam's life span has been reduced to its half. The coastal line suffers erosion during monsoon when the Arabian Sea is very rough. Of the 560 kms, coastline of Kerala about 320 kms consisting of sandy beaches is subjected to severe

sea erosion. Soil erosion is likely to become only worse in the near future and therefore it calls for greater attention.

Soil Conservation

Since the chief agents of soil erosion are water and wind, therefore, soil conservation must take into account the following facts, such as

(i) Protection of soil from the impact of rain drops.

(ii) To prevent water from concentrating and moving down the slopes in a narrow path

(iii) To slow down the water movement when it flows along the slope.

(iv) To encourage water infiltration in the soil

(v) Reduction in wind velocity near the ground.

Thus several methods can be resorted to for the conservation of soils. These include

(I) Biological methods where conservation is achieved by the use of plant- vegetation cover. *These include*

(A) Agronomic practices in areas with normal farming where vegetation itself is used for soil protection

(B) Dry farming in areas where the rainfall is slow and moderate and where normally farming is not practically possible.

(C) Agrostological method in areas suitable for successful growth of grasses which are used as soil binders to check soil erosion.

(II) Mechanical methods in which conservation is achieved by supplementing the biological methods so as to increase the time of concentration of water and to reduce the velocity of water.

(III)Other methods include gully plugging, stream bank stabilisation and watershed treatment

Biological Methods

A. Agronomic Practices

Agronomic practices for soil and water conservation help to intercept rain drops and reduce the splash effect, help to obtain better intake of water rate by the soil by imporving the content of organic matter and soil structure. They also help to retard and reduce the surface runoff through the use of contour cultivation, mulching, dense growing crops, strip cropping and mixed cropping.

1. Contour Farming

Contour farming affords the most effective method of controlling the runoff by farming across the slopes keeping the same level as far as possible. The plough furrows are of high level and hold the light rains till they are absorbed by the soil. In case of heavy rains, the numerous stems of a dense stand of plants obstruct the stream flow and reaches the velocity of runoff. The ridges and rows of plants placed across the slope, form a continual series of miniature barriers to the water moving over the soil surface. The barriers are small individually, but as they are larger in number they have net effect in reducing runoff and soil erosion, and enhance plant nutrient content. In the Nilgiri Hill, where potato cultivation on red laterite soil caused the soil loss of 39 feet per hectare per year, restoring to simple contour farming brought down the erosion to 15 feet per hectare per year

2. Mulching

Mulching is the process of placing matter on the surface of the soil in order to suppress the growth of weed seedlings or to reduce temperature fluctuations at the soil surface or to reduce evaporation and also to prevent soil from being blown or washed away Some such materials as maize stalks, cotton stalks, tobacco stalks, potato tops, etc , are used as mulch (a protective layer 2-3 inch thick layer formed by the stubble, i.e., the basal parts of herbaceous plants especially cereals attached to the soil after harvest). Later on those materials get incorporated into the soil and become humus. Mulching is highly beneficial in the semi arid and dryland tracks of India.

3. Strip Cropping

Strip cropping is one form of rotation. Strip cropping employs several good farming practices including crop rotation, contour cultivation, proper tillage, stubble mulching, cover cropping, etc. Strip cropping is of many different forms.

(a) Contour Strip Cropping.

Contour strip cropping is the growing of soil exposing and erosion permitting crops in strips of suitable width across the slopes on contour alternating with strips of soil protecting and erosion resisting crops. Contour strip cropping shortens the length of the slope, checks the movement of runoff water, helps to desilt it and increases the absorption of rain water by soil. Moreover, the dense foliage of erosion resistant crops prevent the rain from beating the soil surface directly. Groundnut, moth bean and horse gram are the most efficient and suitable crops for checking erosion.

(b) Field Strip Cropping.

It is the planting of farm crops in more or less parallel strips across fairly uniform slopes but not on exact contours.

(c) Wind Strip Cropping

It involves planting of tall growing crops such as jowar, bajra, maize and low growing crops in alternately arranged straight and long but relatively narrow parallel strips across the direction of prevailing winds. It, however, does not follow the contours. Wind strip cropping has actually stopped the advance of the Rajasthan desert into southern Haryana and southwestern Uttar Pradesh. Similar attempts have been made in the coastal belts of India by planting *Palmyra, Acacia auriculaeformis, A planiformis,* that thrive under saline conditions, moist breeze and the onslaught of tidal winds and waves.

B. Dry Farming

Dry farming is the technique of cultivation of land and those areas where the rainfall is meagre. Due to insufficiency of rainfall, the vegetative cover is always small and

limited Thus, these fields are subjected to erosion by both water and wind. The very purpose of dry farming is to grow crops to restrict further erosion of soil and make the best use of such lands for agricultural production at the same time. The dry farming techniques are directed towards the conservation of soil moisture and its timely utilisation

C. Agrostological Methods

The function of grasses is not only in being leguminous but also in controlling the soil and water losses. Strips of grass in between the growing fields restrict the flow of water and thus control erosion. In those areas where the agricultural practices and mechanical devices prove futile the best way to control erosion is to grow grass A grassed waterway is constructed according to a proper design and a vegetative cover is established to protect the channel section against erosion caused due to concentrated flow In the Doon Valley under humid subtropical climate Panicum repens was the best suited grass Other suitable grasses were Cynodon plectostachyrus, Cynodon dactylon and Paspalum notatum. The suitability of grass was based on the cover it gave, the ease with which it was established and the forage it provided. Agrostological methods include

(i) Ley Farming

It consists of growing grass in rotation with agricultural crops. It, thus, improves the fertility of the soil and checks soil erosion. Guinea grass (*Panicum maximum*) is an important tropical grass. It thrives well in warm moist conditions and in almost all types of soil except waterlogged areas. Though the potential of Guinea grass is well known, its capacity as a bioagent for soil conservation has rarely been exploited. The perrenial grass with a deep and prolific root system can bind the soil together, thus preventing the loss of the valuable surface soil.

On slopy lands it adapts well with other annual crops of a multiple cropping system in alternate rows, to accomplish this task. In high rainfall areas, where soil erosion is a serious problem, Guinea grass can be used to achieve the twin objective of fodder production and soil conservation. In slopy terrain where earthen bunds are used to prevent soil erosion, this fodder grass can be raised on the bunds at an interval of 20 cms., between plants, with three slips per hill. This will strengthen the bunds.

(ii) Retiring Lands to Grass

It involves growing grasses on such lands where major proportion of the top soil has been eroded.

II. Mechanical Methods

Mechanical methods are adopted to supplement the agronomical practices when these are not quite effective. Mechanical measures include basin listing, subsoiling, contour bunding, graded bunding and bench terracing on steep slopes. Three principles are observed in designing these measures to control erosion.

(i) Increasing the time of concentration and thus allowing more runoff water to be absorbed and held by soil.

(ii) Dividing the slope into several short ones for the purpose of minimising the velocity of water.

(iii)Protection against damage due to runoff.

1. Basin Listing

Basin listing involves making some interrupting basins by a basin lister. This method helps holding rain water and is quite effective with regard to those soils which have somewhat greater capacity to retain water as being placed on mild slopes (less than 2 per cent).

2. Subsoiling

In subsoiling the hard and impermeable subsoil is broken with the subsoiler. This operation does not involve the inversion of the soil but improves the physical condition of the soil, promotes greater moisture penetrates into the soil and reduces runoff thereby minimising soil erosion.

3. Contour Bunding (Level Terraces, Ridge type Terraces)

Contour bunding also called level terraces or ridge type terraces consist of making comparatively narrow based embankment at intervals across the slope of the land on a level that is along the contour. It is an important measure that conserves soil and water in arid and semi arid areas with high infiltration and permeability.

4. Graded Bunding or Channel Terraces

Graded Bunding or Channel Terraces involves making bunds. Graded bunding has been used in areas receiving rainfall of more than 80 cm per year irrespective of soil texture Graded bunding may be broad based or narrow based. A broad based graded terrace consists of a wide low embankment constructed on the lower edge of the channel from which the soil is excavated. The excavation of the channel is at a suitable interval on a falling contour with a suitable longitudinal grade. Broad based terracing is recommended where farming is practiced with tractors.

5. Bench Terracing

In bench terracing, a series of platforms are made having suitable vertical drops along contours on suitably graded lines across the general slope of the land. Bench terracing can be either 'table top' or sloping outward or inward, with or without a slight longitudinal grade. This depends largely on the rainfall of the tract-poor, medium or heavy. Bench terracing helps to retain the soil moisture, facilitates manure and fertilizer use and also facilitates the application of irrigation whenever possible. Bench terracing helps to carry out intensive farming on steeply sloping and undulating land.

6. Contour Trenching

This method involves the excavation of trenches of suitable length about two feet deep and one foot broad across the slope of the fields. The soil which is taken out from the trenches is used in the formation of bunds along the lower edges. Tree seedlings are planted along these trenches.

III. Other Methods

1. Controlling Gully Erosion

Gully erosion control is essential and urgently requires to be implemented in India

can be effectively controlled by engineering means and by planting of trees and shrubs in ravines

(a) Engineering means

Engineering means involve building of small dams or plugging the gully **Gully plugs** protect the gully beds by reducing the speed of runoff water, redistributing it, increasing its percolation., encouragingnditions, there is wide diversity as regards to its geological setting, physiography, climate and vegetation, therefore, it is silting and improving soil moisture regime for establishing a plant cover.

Gully plug are of various materials, e.g , brushwood, live hedges, earth, sand bags, bricks, masonary and boulders and these have been tried in India All types of gully plug are effective either in retaining or retarding the runoff. The earth is the cheapest and the most readily available material and it is, therefore, easier and economical to construct the earthen gully plugs. If material is available, boulder gully plugs are equally effective. The problem with brushwood as gully control material is that it cannot survive an attack of white ants and are likely to disintegrate within a couple of years. The engineeering measures are best supplemented by planting trees and shrubs in the ravines. The slopes can be stabilised by sodding with grasses like *Gencherus ciliaris Dicanthium annulatum and Erempogon Feveolaus. Dicanthium annulatum and Cenchrus ciliaris* which have been found suitable in Gujarat and in the ravines on the bank of the Yamuna river. The Sukhomajri experiment near Chandigarh achieved considerable success in halting expansion of badlands created by severe erosion. Within a decade, the sediment load of a major stream declined from 50 tonnes per hectare per year as a result of various conservation measures. Efforts made in the ravinelands of the Yamuna (southwest Uttar Pradesh), the Chambal (Madhya Pradesh), the Sabarmati- Saraswati (Gujarat) and the Mayurakshi likewise paid dividends. In the Damodar catchment area the sediment yield has

gone down by 50.23 per cent and in the Mahanadi (Orissa) at Hirakud and the Machkud by 13.11 per cent and 31.95 per cent respectively.

The best landuse of ravine lands is to retire them to permanent vegetation comprising grasses and trees. This type of landuse is must for deep and narrow gullies.

The natural tree species of the ravine land of Gujārat comprise *Accacia nilotica, A. senegal, A Leucophloea. Azadirachta indica, Albizzia lebbeck, Aeronia elephantum, Orosopis spicigera*, etc. These species make very good growth when grazing and other biotic interferences are checked. These species are further helped by silvicultural operations Afforestation has been quite successful in the ravines of Gujarat with species like *Acacia nilotica, Euclayptus camaldulensis, E. citriodora, B hybrid, Pongamia glabra, Tectona grandis*, etc.

Watershed Treatment

Soil loss can best be tackled by covering the watershed with vegetation - multistratal trees, shrubs and grasses. The deteriorated area or threatened area is covered with quick growing plant species followed by deep root long maturing appropriate trees to restore the original condition. In the Chambal ravines planting of sheesham, *khair* alongwith fodder grass *Dicanthum annulatum* has reduced the peak discharge of runoff from 0.27 m3/sec. to 0.12 m3/sec. within 7 years.

In the Ramganga catchment in the Kumaon Himalaya, conservation measures have reduced the sediment discharge rate from 0.18 million hectare/km2 per year in 1958-62 to 0.14 million hectare/km.sq. per year in 1967-71. Watershed conservation measures likewise in Damodar valley in Bihar and in the Hirakud and the Machkud valleys in the Mahanadi basin have yielded drastic results

Streambank Stabilisation

The channel beds and sides can be protected by trees and bushes on levees or embankments. These trees can be willows (*Salix tetrasperma*), napiers (*Pennisium purpureum*), nara (*Arundo donax*): beshram (*Ipomoea carnea*), Shamalu (*Vitex negundo*), etc.

The channel grade is flattened to keep erosion at a minimal level. The energy of water is reduced by making stilling basins (which serve as shock absorber) or making the beds irregular by putting a series of drop structures with adequate aprons and spellways. Spurs are built to keep the currents from the valley slopes and ensure stability of the banks and embankments. These structures deflect the currents and reduce their velocity.

Saving coasts and nourishing beaches

The coasts can be saved by restoring to many engineering solutions such as building offshore breakwaters, seawalls and backheads. Groynes of all, have proved more successful in arresting erosion by building beaches, although there is always some erosion downrift. The groyne at Veltoor over Varkala has successfully protected th coast for almost a century now but those of Cochin harbour and Moplah Bay have not yielded the desired result.

Jetties are massive structures generally in pairs and are constructed along the channels of estuaries and lagoons and in harbours. They not only retard erosion but also improve nevigation by halting or minimising accumulation of sediments

Beaches are nourished by the building of groynes and jetties and by pumping watery sediments from the offshore belts and filling them on the downdrift sides of the groynes. These measures have helped to build the Parakhad beach of Kerala.

Controlling Landslides

Landslides are a more serious problem in the Himalaya than elsewhere Control methods depending on the kind of materials available in the area, the cause of the problem, the type and the rate of movement of the slide. These factors vary so greatly from slide to slide that details of remedial measures are required to be tailored with each slide.

Land Capability Classification

It is now clear that the natural factors apart, improper use of land is lately responsible for erosion and deterioration of land, with a consequent fall in land productivity. Because the factors affecting soil use and erosion may vary so widely and

the combinations of factors are so numerous, some grouping of land according to its capability is needed. This is the key to the problem of soil erosion.

For optimum results, every unit of land should be managed in accordance with its inherent characteristics, capability and limitations of the climate and local hazards. The factors which determine the land capability are the major soil characteristics of the land, e g , the texture of the top soil, its effective depth; permeability of the top soil and subsoil and associated land features, e.g., the slopes of the land; the extent of erosion; the degree of wetness and its susceptibility to overflowing and flooding.

Soil Salinisation and alkalinisation

Distribution and Nature

Soil salinisation and alkalinisation is a severe problem in the irrigated areas of the country where drainage conditions are not very good. About 7 million hectares of land in India are affected by soil salinisation. They are mostly found in the irrigated tracts of the Punjab, Uttar Pradesh, Haryana, Rajasthan and also in Gujarat, Maharashtra and coastal regions.

Application of irrigated water in areas of restricted natural drainage or where the water table is high causes waterlogging. Waterlogging causes dissolution of salts from the soil Evaporation of the stagnant water in the area causes a thin film of salt to be left behind on the surface. The saline soils contain free sodium and chlorine, but when sodium ions predominate in the soil solution with additional presence of carbonates, then the soils are alkaline.

Soil salinity and alkalinity has many adverse effects, such as

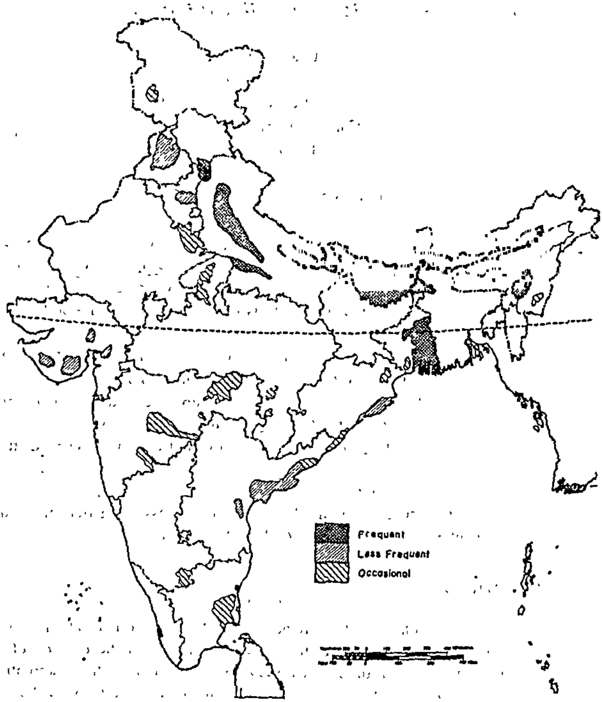
(a) Lowering of yields and crop failure.

(b) Limiting the choice of crops because some crops are sensitive to salinity and alkalinity.

(c) Rendering the quality of fodder poor.

(d) Creating difficulties in building and road construction

Fig.6.4. Extent of waterlogged soils in India



(e) Causing floods due to reduced infiltration, leading to crop damage in the adjoining areas.

Control of soil salinisation and alkalinisation

The saline and alkaline soils can be treated by restoring to five phase programme

1. Providing outlet for water to drain out excess water and lower the water table. At the same time, suplementary efforts must be made to seal all points and strips of leakage from canals, tanks or ponds by lining them.

2. Minimise the use of water application.

3. Planting salt tolerant vegetation such as barley, pearlmillet, raya, cotton spinach, date palm, and certain grasses used as fodder. Crop rotaton involving dhaincha-cotton in the Deccan plateau, dbaincha-rice in Uttar Pradesh and dhaincha-rice-berseem in the Punjab and Haryana have been very helpful.

4. Liberal application of gypsum (which contains 70-80 per cent $CaSO_4.2H_2O$) in the upper 15 cms. thick soil to convert the alkalis into soluble compounds: The $CaCO_3$ of the alkali soil can be removed by addition of sulphuric acid or acid forming substances like sulphur and pyrite Also organic residues such as rice husks and rice straw may be added to promote formation of mild acid as a result of their decomposition.

$CaCO_3 + H_2SO_4 \rightarrow H_2CO_3 + CaSO_4$ (weak carbonic acid)

5. Salts can also be flushed by flooding the fields with excess water but this would invite problems like downstream pollution by highly saline water.

Soil Laterisation

Soil laterisation takes place in those region where the climate is of alternate wet and dry type. During the rainy season, the torrential rains leach the top soil of its nutrients and other materials in the lower horizon. In summer when the evaporation is very high all the nutrients along with iron and aluminium are drawn on the top surface by capillary action. This forms a very hard brick like layer. *This process is particularly prevalent in those regions where* **jhum cultivation** is practised. *Jhuming denudes the top layer of its vegetation cover allowing greater leaching during the rainy*

season. In the summer the top soil is baked by the blazing Sun forming laterite Thus, these type of soils are being constantly formed in regions of shifting cultivation

Government's effort

Indian Government has taken many steps for the conservation of soils. Soils and water conservation measures have been accepted as one of the essential inputs for increasing agricultural productivity in the country. These programmes were first launched during the first plan. From the very beginning, emphasis has been on the development of technology for problem identification, formulation and implementation of problem oriented schemes, enactment of appropriate legislation and constitution of policy coordination bodies. While conceptual framework of soil and water conservation activities in the country has not changed, the content of the programme has undergone considerable revision during successive five year plans. The main objective of the scheme in operation are

1. to minimise the process of erosion and land degradation.
2. to restore degraded lands.
3. to ensure rebuilding of internal fertility of soil through organic recycle particularly in resource poor regions.
4. to ensure availability of water and soil moisture.
5. to create micro level irrigation potential through water harvesting.
6. to enlarge effective productive exploitation zone to deeper soil profile by adopting a mixed and comparison farming system.
7. to increase aggregate biomass production.
8. to generate employment through continuous adjustments in optimum landuse planning and to ensure collective security against recurring droughts and floods.

Till the end of 1995-96, an area of 3.61 million hectare out of the total treatable area of 20.76 million hectare in the catchments of River Valley Project has been treated,

which comes to 15.22 per cent of the treatable area. Similarly in the case of Flood Prone River Scheme till the end of the 1995-96, an area of 0.775 million hectare out of the treatable area of 7.56 million hectare has been treated, which comes to about 10.25 per cent of the treatable area. A Centrally sponsored scheme for reclaimation of alkali (*usar*) soils initiated during the Seventh Five Year Plan is continuing in Haryana, the Punjab and Uttar Pradesh The major components of the scheme include assured irrigation water on farm development works like land levelling, deep ploughing, community drainage system, application of soils amendment, organic manure, etc. It is 50:50 funding between the Centre and the concerned state on identified components. Since the inception of the scheme, an area of 4.32 lakh hectare of land has been reclaimed with Central investment of Rs 59 67 crore upto 1995-96. The scheme for control of shifting cultivation (CSC) was implemented with cent per cent special Central assistance in the northeastern states, Andhra Pradesh and Orissa till 1990-1991 wherein 26,532 families were selected (out of which 18,842 families in the northeastern states) for meeting held in October 1990 the scheme was transferred to the state sector with effect from 1991-92, i e , one year before the terminal year. An expenditure of Rs 61.72 crore has been reported till 1991-92 against a release of Rs 55.67 crore. The Planning Commission has approved for the revival of the scheme only for the northeastern states from 1994-95. An outlay of Rs 15 crore has been provided for this purpose. The Scheme for Watershed Development Project in Shifting Cultivation Areas (WDPSCA) of North Eastern States is to be implemented in accordance with the guidelines of the ongoing Centrally sponsored scheme for National Watershed Development Project in the Rainfed Areas (NWDPRA). Up to 1995-96, an amount of Rs 29.24 crore has been released to the states under the scheme

Till here.

Important Words

Parent Material	**High level laterites**	**White alkali**
Kaolinite	**Nitosol**	**Gully Plugs**
Jhum Cultivation	**Salinisation**	**Laterisation**
White Alkali	**Alkalinisation**	**Marginal Soils**
Leaching		

7

FLOODS

Full chapter

Introduction

Flood is a state of high water level along a river channel or on coast that leads to inundation of land which is not normally submerged. Flood is an attribute of physical environment and thus is an important component of hydrological cycle of a drainage basin. Flood is a natural phenomenon in response to heavy rainfall but it becomes a hazard when it inflicts loss to the lives and properties of the people.

The flood affected area increased from an annual average of 6.48 mha in the 1950s to over 9 mha in the 1970s and 1980s. This increase is definitely an indication of the country's growing flood proneness.

The Rashtriya Barh Ayog (RBA) or National Commission on Floods, set up by the Government in 1976, because of the growing public concern over increasing floods, first provided statistical evidence of the problem. The commission took the maximum area affected by floods in a state, in any year, as its flood prone area and in this way added up the flood prone areas of all the states to get the flood prone area of the country. This method underestimates the problem because there is no guarantee that floods in any year will affect only those areas which were affected during the maximum flood year. Yet the commission found that the country's flood prone area which had been estimated at about 25 mha during the 1960s went up sharply to 34 mha by 1978 Since 10 mha had been covered by flood protection measures by then. It is well known that these measures often fail during high floods. The commission put the country's flood prone area at about 40 mha. This report, thus, revealed a rapid increase in flood proneness in just over a decade. Most of these areas (Fig 7.1) lie in the Ganga basin,

the Brahmaputra basin comprising the Barak, the Tista, the Torsa, the Subansiri, the Sankosh, the Jaldhaka, the Dibang, the Dihang and the Luhit; the northwestern river basin comprising the Jhelum, the Sutlej, the Beas, the Chenab and the Ravi and the notorious Ghaggar, the Peninsular river basins comprising the Tapi and the Narmada, the Mahanadi, the Baitarni, the Godavari the Krishna, the Pennar and the Kaveri and the coastal regions of Andhra Pradesh, Tamil Nadu , Orissa and Kerala. The most flood prone basins are those of the Ganga and the Brahmaputra in Uttar Pradesh, Bihar, West Bengal and Assam, followed by the Baitarni, the Brahmani and the Subarnarekha basins in Orissa. These five states are the most flood prone. But the commission, analysing flood damages in the late 1970s, pointed out that during the period 1976-78, floods were also experienced in Andhra Pradesh, Rajasthan, Haryana and Gujarat, i.e., "in areas not usually affected." The share of damages of the second group went up from around 20-25 per cent to about 50 per cent of the total. Even in the chronically flood prone Uttar Pradesh and Bihar, the flood affected area has been increasing.

Table 7.1: Flood prone areas of India

States	1953-78 (mha)	1953-88 (mha)
Andhra Pradesh	1.39	1.39
Arunachal Pradesh	-	0.00
Assam	3.15	3.82
Bihar	4.26	4.26
Goa	-	0.00
Gujarat	1.39	1.39
Haryana	2 35	2.35
Himachal Pradesh	0.23	0.39
Jammu & Kashmir	0.08	0.51
Karnataka	0.02	0.26
Kerala	0.87	0.87
Madhya Pradesh	0.26	0.26
Maharashtra	0 23	0.23
Manipur	0 08	0 08
Meghalaya	0 02	0.10
Mizoram	-	0.00

Nagaland	-	0.01
Orissa	1.40	1.40
Punjab	3.70	4.05
Rajasthan	3.26	3.26
Sikkim	-	0.02
Tamil Nadu	0.45	0.45
Tripura	0.33	0.33
Uttar Pradesh	7.34	7.34
West Bengal	3.77	3.77
Delhi	0.07	0.07
Pondicherry and Other Uts	0.01	0.05
Flood Prone Area	34.65	36.66

Causes of Floods

Floods result from an unfavourable combination of meteorological and physical condition of the drainage basin which lead to excessive water run-off and consequent relative reduction in carrying capacity of channels leading to bankfull conditions. The causative factors, in recent times, have been aided and accentuated by human impact The various conditions responsible for floods are:

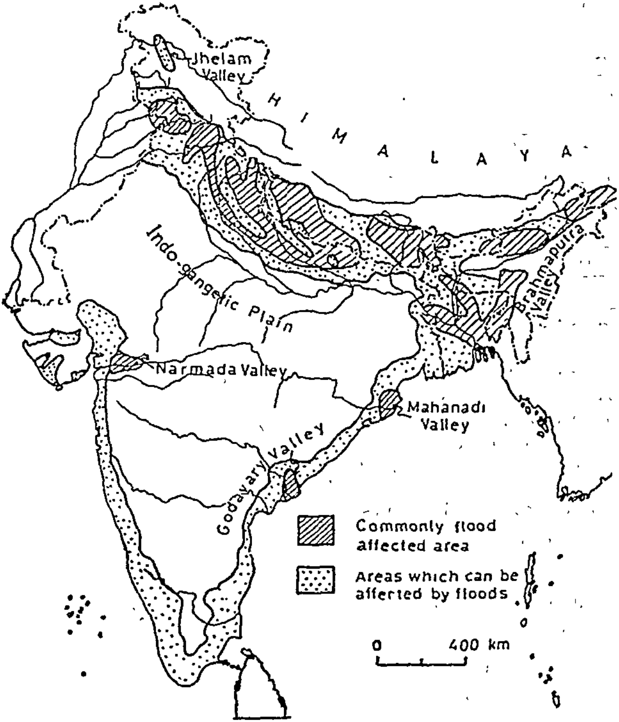
(A) METEOROLOGICAL CONDITIONS

1. Cyclones.
2. Cloud burst.

(B) PHYSICAL CONDITION

1. Narrow outlets.
2. Large catchment areas.
3 Lack of well developed drainage channe
4. Siltation and raising of channel.
5. Presence of unconsolidated soil.

Fig.7.1. Flood prone areas of India



6. Blocking effect of landslides.
7. Meandering

(C) HUMAN IMPACT

1. Construction of dams and reservoirs.
2. Bursting of dams
3. Deforestation.
4. Faulty slope practices.
5. Construction of embankments

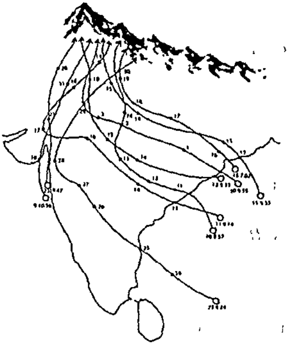
Meteorological Causes:

1. Heavy rainfall.

Heavy incessant and prolonged rainfall for long period is the basic cause of floods because enormous amount of water gets collected on the surface flowing as run-off As the volume of water increases, the river banks are overtopped and consequently the adjoining areas are inundated. India is one of the world's wettest countries with an annual average rainfall of 115 cms. But nearly 80 per cent is received from June to September in all the states (except Tamil Nadu) during the southwest monsoons. It usually exceeds 100 cm in areas east of 78° E longitude It extends to 250 cm along the entire west coast and Western Ghats and over most of Assam and sub-Himalayan West Bengal. Because of this seasonal concentration of rainfall, rivers remain practically dry during summer while in rainy season they swell, overflowing their banks

High intensity rainfall giving average annual amount of 250 cms. in the plain area and 500 cms. in the hilly sector in Assam periodically causes floods in the Brahmaputra Valley. High rainfall in the Himalayas and in the plains cause disastrous floods in the Himalayan rivers draining through the North Indian plains Higher magnitude of rainfall coupled with a larger catchment area leads to a greater volume of overland flow. It must be noted, however, that although the total amount of rainfall in the catchment has changed little in the past several decades (though there may be variation in intensity from year to year) but the severity of floods has steadily increased over the years.

Fig.7.2. The impact of storms in the Himalayas



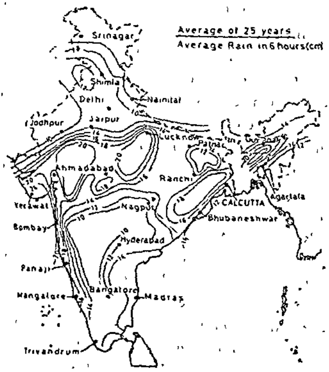


Fig.7.3. The impact of cloud bursts and the areas affected by it.

2. Cloudbursts

Excessive rain within a short period is called a cloudburst. Cloudbursts are very common in the Himalayan region, Orissa, and central and western India including Rajasthan and Gujarat. In 1979, within a single day there was 37 to 50 cm. rainfall in Saurashtra. In 1979 cloudburst was responsible for breaking of the Machu Dam II following incessant rains and consequently, heavy flood lower down. This rainfall was responsible for the destruction of entire Morvi town. In 1978, a cloudburst in the Great Himalayan Range slipped a huge amount of morainic debris that led to dam formation Later, when the dam burst, it caused widespread havoc.

3. Tropical Cyclones

Cyclones are the most important cause of floods in the coastal areas. Certain parts of our vast coastline especially Andhra Pradesh, and Orissa coast in the east and the Gujarat coast in the west are particularly prone to onslaught of cyclonic storms which originate and develop over warm seas. Accompanying these violent storms are huge tidal waves and intense rainfall. The tidal waves cause widespread inundations in the coastal belts. The heavy downpour which accompanies cyclones inevitably brings flood in its wake. In November 1982 and in 1983 in Saurashtra, cyclones resulted in overflowing of 27 dams some by over 2m.

Floods due to cyclonic storms are purely a natural calamity. Man has no hand in it but some precautionary measures can be taken which minimise the impact of cyclonic storms.

Whatever be the cause of heavy rainfall, cloudburst and cyclones they all lead to flooding conditions and even if some measures by way of building of dams have been taken to check flooding there is every likelihood that dams will overflow and finally burst bringing even more devastation in its wake.

Physical conditions

1. Large catchment area

A large catchment area collects water from a larger area thus even if the rainfall conditions are not fairly heavy, chances of flooding in the consequent stream is h

. 'e ' , More rainfall (more water) → more runoff (less infiltration) → Greater drainage

(c) Largely natural (b) But by humans also natural factors human factors natural factors

simply because the volume of water collected from such a larger area becomes very large The catchment areas of the Ganga and the Godavari are very large and the volume of the water carried by these rivers is also very large.

by disturbance of natural climate & ecosystem balance by more pollution, gases etc.

2. Inadequate drainage arrangement

Even if the catchment area is quite small and the rainfall in the catchment area is not heavy, flood occurs because water, if it does not drain quickly, accumulates and leads to flood. The inadequacy of the drainage arrangement is because of different reasons in different regions of the country.

(a) Ill developed drainage channels. In the Punjab and Rajasthan particularly, the drainage channels are not well developed. Heavy spells of rainfall in these arid and semi arid regions cause flash floods as the rivers are unable to accommodate enormous volume of water in the absence of natural drainage system. Moreover, in these regions, the soil is largely unconsolidated and run-off causes enormous transfer of these soils. The deposited soil in turn chokes and blocks the natural drainage thus leading to floods.

(b) Reduced carrying capacity of rivers. The capacity of channels conveying water is diminished by the accumulation of sediments derived from severe erosion in the catchment areas. The deposition of the sediment on the beds restricts the passage of the water and thus the carrying capacity of the channel is reduced. This results in spreading of the flood water on the adjacent plain. The extensive flooding in eastern Uttar Pradesh and northern Bihar especially by the Narayani and the Kosi rivers is primarily due to the reduced carrying capacity of the rivers choked with sediments which have been derived from accelerated erosion in the Himalayan region and inadequacy of slope in flood plains.

(c) Blocking of natural flow by landslides. Landslides caused either by earthquake or other natural and anthropogenic factors lead to impoundment of water and a consequent raising of the water level leading to bankfull conditions. If the 'natural dam' bursts, it causes disastrous floods downstream. This normally happens in the Himalayan region and this is what happened with the Bhagirathi river in 1978 when a landslide caused a dam formation. The bursting of this dam, 14 hours later, caused widespread havoc up to Uttarkashi and wiped out the hamlets of Gangnani and Dabrani on the pilgrim route to Gangotri.

(d) Meandering of the rivers. Sinuous and meandering course of rivers obstruct the normal discharge of water thus reducing the velocity which delays the passage of water resulting into stagnation of water. As a result, the meandering loops are flooded. This type of situation prevails in the lower reaches of the Ganga, the Brahmaputra, etc.

(e) Formation of sand bars. Sand bar formation is a common phenomenon in the coastal regions particularly near estuaries. Longshore drift which leads to formation of sand bars, chokes the mouth of estuaries and deltas This impedes the natural drainage, particularly, in times of heavy rainfall when the river carries a greater volume of water. In the delta areas of West Bengal and Orissa the problem has been aggravated by the influence of sea tides which deposit silt on the mouth of the rivers and also in the drainage channels. This leads to a constant deterioration in the discharge capacity of the river.

Anthropogenic Factors and Human Impact

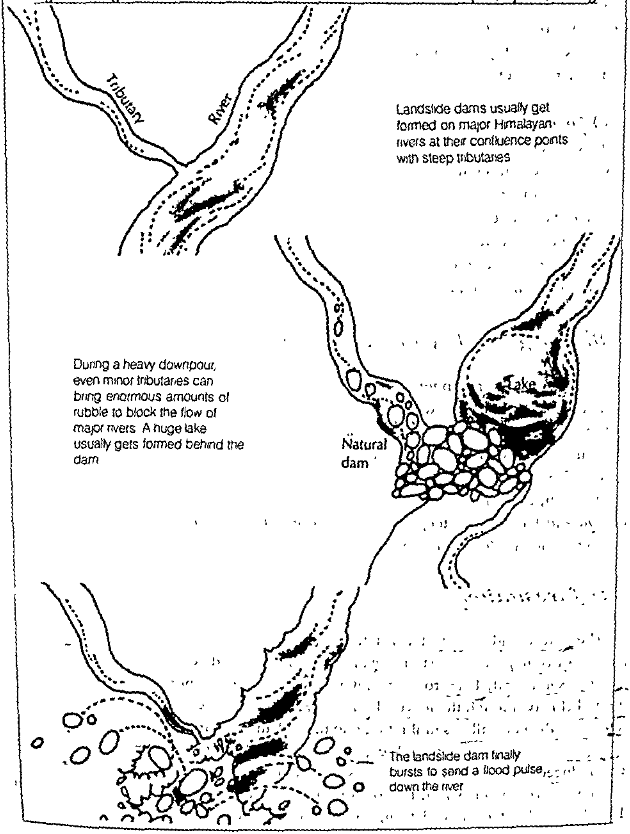
Floods are natural phenomena, and if certain meteorological and physical conditions are present, floods are bound to occur. But, recent times have witnessed a greater incidence of flooding. This has been largely due to human impact on the physical conditions. The flood discharge of a stream depends on the amount of run-off or the ground flow of rainwater. Run-off is determined by the amount of infiltration of water which, in turn, is determined by the nature and extent of vegetation, texture of the soil and length and steepness of the slope. The human impact has altered all of these components. The most important of all is the destruction of forest cover

1. Deforestation

it decreases runoff. Raindrops are intercepted by forest canopy and thus reach the

Thus wherever man has resorted to indiscriminate deforestation, as in Siwaliks, Lower Himalayas, Chhotanagpur plateau, Western Ghats and elsewhere floods have become

Fig.7.4. Diagram to show the formation of natural dam and its impact upon bursting



a rule in the downstream areas. This is evident in Tista and Torsa in West Bengal, Chambal in Madhya Pradesh, Gandak in Uttar Pradesh and Kosi in Bihar, etc. In view of the fact that the country has lost 86 per cent of its forest cover (and Himalayan region 77 per cent of its cover) it can be clearly understood why there has been a phenomenal increase in the recurrence and severity of floods despite no perceptible change in the rainfall pattern in the last century. Imp

2. Siltation

Higher surface runoff resulting from deforestation additionally accelerates erosion and increases the sediment load of the streams. Increased sediment load causes siltation of river beds and filling of the valleys. This gradually raises the river bed and decreases the cross sectional area of the valleys and hence, reduces the water accommodating capacity of the river valleys. In south eastern Nepal the beds of the rivers in the 'Bhabhar' belt are rising at the rate of 15-30 cm/yr. The bed of river Kosi in Bihar is now at a higher level than the flood plain, the river flowing within considerably raised levees. Raising of the channel to a greater or less degree has also been responsible for floods in the Gangetic plain and the Brahmaputra plain.

3. Faulty agricultural practices

In India, valley side slopes of the rivers are ploughed down to the channel, transverse to the contours. This is done to dry out the moisture which had accumulated during the wet *rabi* season. After the crops are harvested, the ploughed fields are baked by the blazing sun in the summer and the loose soils become extremely dry. With the first showers in the coming rainy season, the loose soils get saturated with water and slump into the river bed following overland flow. The river beds thus get gradually silted. Simultaneously, the cultivation of valley side slopes reduces the gradient of river banks finally flattening the valley. As the flattening gradually proceeds, the water accommodating capacity of the river decreases and the river takes very little time in attaining bankfull conditions. The water then spreads over the valley sides inundating the low lying flood plains.

4. Faulty irrigation practices

In the Punjab, Haryana and western Uttar Pradesh there is a network of canals in the alluvial formation. The constant seepage of water from the canals raises the water

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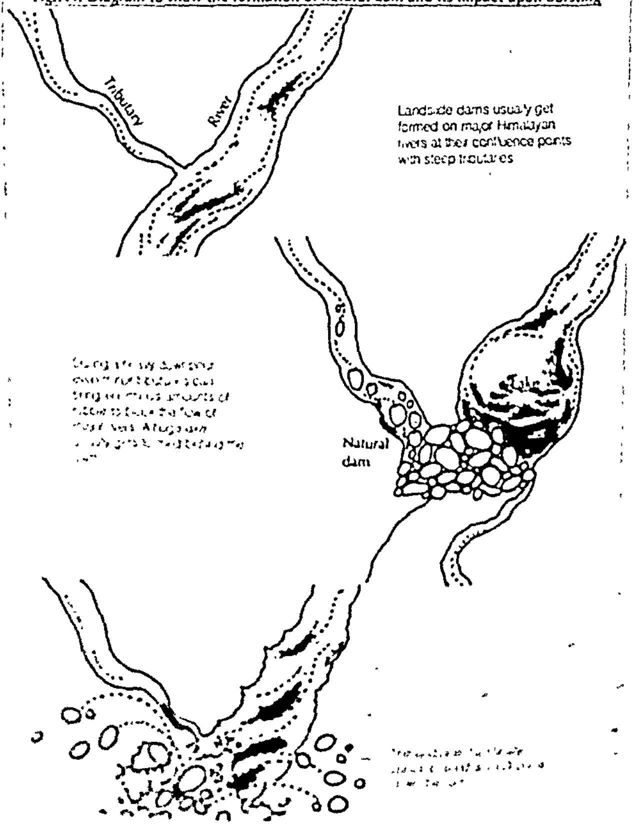

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Soil gets saturated absorb water & rainfall cause flood

table in the adjoining areas. With further application of water for irrigation, in these regions of inadequate drainage a condition of waterlogging arises. Under these conditions, even if rainfall is not so heavy, the entire rainfall flows as surface runoff because the ground does not absorb the water, bringing floods.

5. Increasing urbanisation

Increasing urbanisation helps to increase the surface runoff and thus the dimension and magnitude of floods The construction of roads, building, pavements, etc., reduces the infiltration capacity and increases the surface runoff. The increased surface runoff finds its way through the drains into the nearby stream locally increasing the volume and magnitude of floods. Additionally, urbanisation has also led to siltation of river beds caused by dumping of garbage from the nearby centres, extension of settlement in the low lying areas, filling up of nallas (urban drains), construction of bridges, roads, embankments, etc Consequently the drainage capacity of the river has been reduced.

Water Accomodating capacity its also reduced.

Although the causes of floods are many and each individual cause may bring about flood, floods actually result from a combination of these causes. For example, two factors, namely, heavy precipitation and deforestation have been the most important causes of floods and although there has not been a change in the overall rainfall pattern, deforestation has increased surface runoff and consequently incidence of floods An attempt to integrate the various factors has been made in Fig 7.5.

Consequences of Floods

Floods are gradually becoming more and more damaging as they appear with an increased frequency, intensity and magnitude. The most important impact of floods is the loss of life and property. Indirect losses result from the breakdown of the communication, disruption of rail and road traffic and other essential services whose restoration may cost crores of rupees.

The impact of flood was not, perhaps felt to the same extent in the past as it is being felt now because earlier only fewer people lived on the land and there was no such proliferation of industrial activity and other works. Now with an increase in population, areas close to the river have also become habitated. The principle *where a river has the right of way stay out of its way* is not followed by the people who have little option in setting themselves or locating industrial projects. Floods have

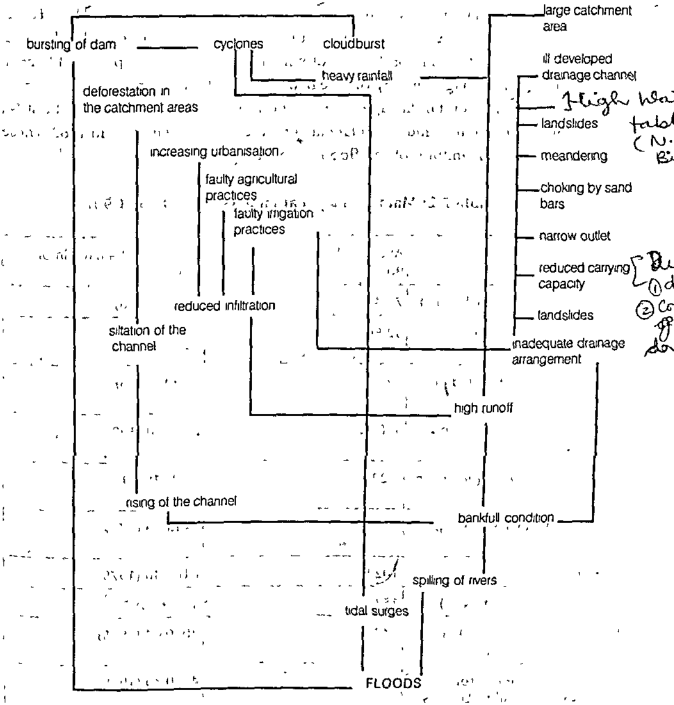


Fig.7.5. A model of flood generating factors

caused heavy damage on nine occasions in the last 40 years - 1955, 1971, 1973, 1977, 1978, 1980, 1984, 1988, and 1989 On an average, the area affected by floods annually is about eight million ha, out of which the cropped area affected is about 3.7 ha. (Tables 7 2 & 7 3) Rashtriya Barh Ayog has assessed the maximum area prone to the floods in the country to be about 40 million ha, out of which 32 million ha is a protectable area. The maximum area damaged in any one year was 17 5 million ha in 1978. the average (period 1953-91) annual total damage to crops, houses and public utilities is about Rs. 9,500 million, while the maximum annual damage was Rs. 46,300 million in 1988. These figures indicate the magnitude of the flood problem in the country.

Table 7.2: Main Damage Parameters (Period 1953-90)

Sl.No.	Item	Average flood damage 1953-90	Maximum drainage in one year (Year)
1	Area Affected (in million ha)	7.94	17.50 (1978)
2	Population Affected (in million ha)	32.86	70.45 (1978)
3	Cropped Area Affected (in million ha)	3.66	10.14 (1988)
4	Value of damage to crops (in Rs crore)	448.32	2510.90 (1988)
5	Houses Damaged (in million Nos)	1.22	3.51 (1978)
6	Value of damage to Crops (in Rs Crore)	132.31	741.60 (1988)
7	Cattle Lose (Nos.)	102.905	618.248 (1979)
8	Human Lives Lost (Nos.)	1532	11316 (1977)
9	Value of Damage to Public Utilities (in Rs crore)	347.38	2050.04 (1985)
10	Total Damage to Crops, Houses and Public Utilities (in Rs crore)	937.56	4630.30 (1988)

Table 7.3 Trend in Flood Damages (Decadewise)

De-sade Years	Area	Population	Damage to	crops	Damages to	houses	Cattle Nos	Human lives	Public Utilities	Total Damages
	(m.ha)	(million)	Area (m.ha.)	Value (Rs.crs)	Nos (lakhs)	Value (Rs.crs)	(lakh)	(Nos.)	(Rs.crs)	(Rs crs)
51-60	6.61	14.71	1.95	44.57	6.02	9.48	0.34	439	6.32	60.34
61-70	5.62	17.41	2.60	106.28	6.00	18.10	0.50	944	19.98	138.38
71-80	9.83	45.53	5.02	440.00	16.52	104.00	1.91	2559	195.92	740.00
81-90	9.44	50.53	4.73	1128.00	18.96	375.00	1.21	1965	1.099.06	2.636.00
Average	8.14	33.00	3.70	450.00	12.00	134.00	1.01	1523	356.00	950.00

Control and Management of Floods

The management of floods implies not letting the excess runoff water flow suddenly and intensely in the drainage network. The various ways in which this can be done by- Reduction in Runoff, reduction of water volume and flood peaks, and by reduction of flood level

These can be further augmented by (i) Protection against inundation, (ii) Flood plain zoning (iii) Flood forecasting.

1. Reduction of runoff

The most effective way of flood management is the reduction of runoff by inducing into the ground in the catchment area. This can be done by with trees that generate larger amounts of litter. The dense many ways

(b)

(a) The canopy intercepts the falling raindrops while the roots, the leaf litter and humus hold water;

(b) Together these encourage infiltration and reduce runoff;

(c) Runoff reduction reduces soil loss, soil erosion and sediment load of the streams;

(d) Reduction in soil erosion and sediment load of the stream prevents siltation and thereby prevents reduction in the water accommodating capacity of the rivers.

In the plains, the runoff can be reduced by artificially inducing infiltration through a large number of dug wells sunk along the beds of ephermal and monsoon kharif channels Pumping in can augment and quicken infiltration of excess flows. Thus a series of dug wells created will serve the purpose of storing and channelising of water. The quantity of water that can be stored underground, will depend on the thickness and holding capacity of the permeable aquifer. The lateral extent of the aquifers in the river basin such as Indo-Gangetic plain is virtually limitless and thickness is considerable Thus, enormous volume of excess water can be stored, preventing the occurrence of floods This method of flood control is very effective and has minimum impact on the environment

(A) → But, afforestation in catchment areas and run off redn will cause the stream to have lesser amt of water and thus it n[ot] reach its ful[l] length thereby depriving the last downstre[am] areas of their water supply.

(2) Reducing flood peaks by volume reduction.

The flood peaks can be reduced by a reduction in the volume of water by resorting to engineering approaches such as construction of storage reservoirs and detention basins Such storage reservoirs impound enormous amount of water during flood period and thus reduce the volume of water carried by the rivers. While a substantial portion of flood water is retained behind the dam, a larger part is allowed to flow down the channel under controlled conditions. India has taken this approach for the control of floods, the most notable effort of which is the project on the Damodar river valley comprising Maithon, Panchet, Konar and Tilaiya and Aiyar dams. However, this approach has not entirely solved the flooding problem because most of these dams are multipurpose dams.

The results as far as flood control is concerned, have been mixed because of conflicting objectives. While flood control demands that the reservoir be kept as empty as possible to arrest any oncoming flood, irrigation and power generation demands that the reservoir be kept as full as possible As a result, dams themselves have become major causes of floods

(A) Similarly construction of smaller hydel projects by tapping outlets of gullies & small rivers streams will hamper the na[tural] collection of water in catchment and a bigger stream or river will ne[ed] fo[r]

They are better

The construction of numerous smaller dams on tributary streams would check flood flows from the sub basin and considerably minimise or even abolish flood hazards in the basin of the main river. Ponds, tanks and surface storage structures also check floods and at the same time also harvest water for dry seasons. A larger number of ponds and smaller basins prevent the need for a larger one in one place. Other type of detention basins include natural depressions such as marshes in the plains and old quarries and mines.

(3) Reducing flood levels.

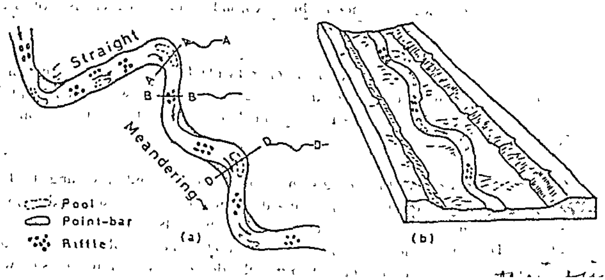
The flood levels can be reduced in various ways-

The excess of flo[od] waters are chan[nelled] into the

(a) Stream channelisation. A network of canals to a large extent reduces the flood hazards but it is not a commonly adopted or accepted measure. The canals serve as temporary storage and holds water as the flood waves moves downstream. In this way, the severity of the flood is reduced.

(b) Channel improvement. Channel improvement by deepening, widening, straightening, lining and clearing out of vegetation and debris increases the flood conveyance capacity of the rivers. Channel improvement is necessarily supplemented by bank stabilisation through construction of ripraps, dykes or spurs and planting deep root trees on the embankments. One of the most efficient way of channel improvement is straightening of the meanders (Fig7 6).

Fig.7.6. Flood Management through channel improvement



The bends in the rivers and meander loops impede drainage and retard the disposal of water To facilitate the discharge and quick disposal of water, the meandering courses, wherever they have become extremely sharp, can be straightened by artificially cutting individual bends or a series of bends. This method can be applied to the meandering rivers in the alluvial plains of the Ganges such as Gandak, Gomti, Rapti, Kosi, etc.

There are many problems associated with channel improvement.

(i) The erosive capacity of the river increases and the channel is enlarged and deepened as the flow becomes swifter

(ii) Channelisation in the upstream part creates flood hazard downstream, as floodwater quickly reach downstream much faster than the lower reaches can discharge their own water Moreover, the flood peaks of the tributaries now coincide with that of the main river and aggravate the flood situation.

(iii) The swifter flow adversely affects the aquatic fauna and flora used to quieter pace of life in the ecosystem, characterised by pools, riffles and point bars, thus reducing the biological diversity.

(iv) The replacement of pools by long stretches of riffles causes the elimination of breeding areas and the higher velocity of the channels may prove disastrous for the organisms

(v) Straightening of meanders needs huge capital outlays, which is not always forthcoming.

Meandering is a natural process of the river and will take place whenever the amount of silt carried by the river is large and whenever the river flows in plains with low gradient. Straightening will do more harm than good as far as flood control is concerned

Imp

(c) Flood diversion. Flood diversion implies diverting and spreading the flood water in marshes, lakes and depressions along the railway lines and highways and spreading it thinly over paddy fields and desert drylands. One such scheme is the Ghaggar Diversion Scheme which diverts about 340 cumecs (cubic meters/second) of water before its entry into Rajasthan into the depressions and the areas between

the sand dunes. In this way, discharge of water in the Ghaggar river during flood stages is kept within safe limits.

(4) Protection against Inundation

One way to control flood and to protect the area against inundation is by construction of embankments to keep the water from flowing into inhabited or cropped areas. The building of embankments is the most widely adopted flood management practice in India. Between 1954 and 1979, 12, 265 kms. aggregate length of embankments were constructed; 246 kms. on the banks of the Kosi, 249 kms. along the Bagmati, 208 on Mahananda, and 317 kms. along Burhi Gandak in Northern Bihar alone. Besides, embankments have also been constructed on the Brahmaputra and also on the Ganga and the Yamuna to save the cities of Delhi, Allahabad, Lucknow, Patna, etc (Fig7.7).

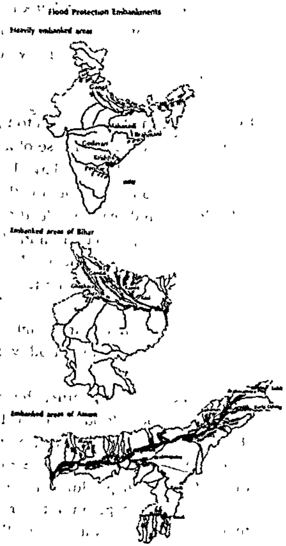


Fig.7.7. Flood Protection embankments in India

Embankments as a flood control measure, however, have severe limitations, specially when constructed to control rivers bringing large loads of silts (Fig. 7.8).

(i) In fact, they are not so much a method of flood control as flood transfer. In other words, walls can be raised to provide protection to an area which because of population density or other factors need more protection but then some other areas will most probably have to face the diverted flood.

(ii) By constricting the river's natural flood plains, embankments lead to a dangerous build up of high flood levels within the embankment area. At the same time they tend to engender a false sense of security in the people inhabiting the surrounding flood plains. Thus, in case of a breach, the flood waters literally cascade upon the surrounding countryside adding considerably to the magnitude and reach of their devastating potential (Fig.7.10). The damage caused by a breached embankment is always greater. Breaches may also be caused deliberately either by the people inhabiting the unprotected areas or by those in the trapped areas for whom the embankments have any way brought nothing other than misery.

(iii) By confining the flood waters to the river channel and a small part of the flood plains, embankments, in case of a river whose bed is rising, force the sediment load, which would earlier have been deposited over a much wider area of the flood plains, to be deposited within the embanked area. This results in higher flood levels, and may also lead to a breach in the embankment. Thus to give the level of protection initially envisaged, progressive raising of the embankment becomes inevitable. A vicious race then commences between the rise of the river bed and the raising of the embankment.

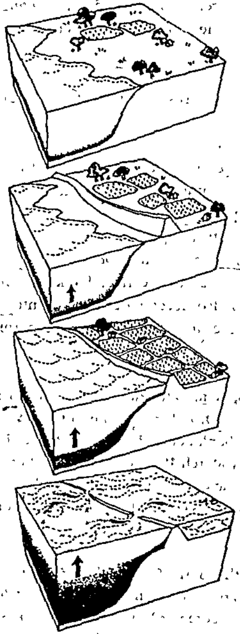
(iv) Sometimes the villages are caught within the embankment and have to bear the full fury of concentrated flood within a smaller area.

(v) Embankments may obstruct the normal drainage of water towards the river leading to a local flood situation The construction of the embankments cuts off the natural drainage from the flood protected areas into the river except through predetermined drainage sluices provided in the embankment. The capacity of the artificial drainage sluices is never equal to the previous waterways available for natural drainage into the river. The problem of drainage congestion, therefore, gets aggravated in the flood protected area (Fig. 7.11). The Rashtriya Barh Ayog (RBA) report states, "Embankments are not a feasible measure of flood protection in cases where the country runoff draining into the river is so large as to inundate appreciatively the area protected by the embankments from river spills, during periods when the river is running at high flood stages."

Drainage congestion becomes still more acute in cases where tributaries join the main river along which embankments have been provided. Tributaries with large catchment areas may carry considerable discharges, which are difficult to

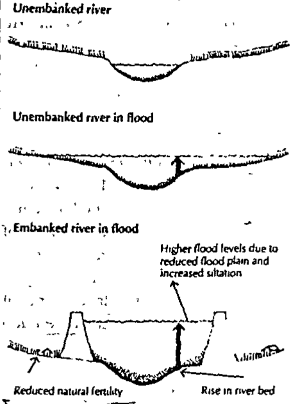
Fig.7.9—7.11. Ecological and social impact of embankments

Social impact of embankments



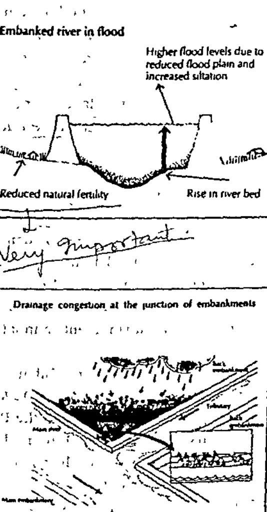
Embankments encourage human occupation of the flood plains by instiling a false sense of security. When rivers in spate breach the embankments a tidal wave hits the villager nearby.

Ecological effects of embankments



Very important

Drainage congestion at the junction of embankments



accommodate in sluices. In such conditions, engineers usually respond with sympathetic or back embankments along the tributary so that the flood water of the main river cannot inundate the countryside by flowing up the tributary and spilling along its bank. But at the junction of the back embankment and the main embankment - particularly the upstream junction - drainage congestion becomes an acute problem. Huge quantities of water can collect at such junctions.

(vi) Within the embankments, the condition of waterlogging leads to many diseases such as malaria and kalazaar.

Thus, although embankments do help to control flood they may at the same time, lead to flood for various reasons outlined above. Thus it has been recommended that the location of and spacing between embankments should be as far as possible, be in conformity with design requirements so that the danger of erosion and breaches is minimised as much as possible. At the same time, embankments must be placed too close to the river banks in order to protect as many villages as possible. This also necessitates further anti erosion works which are expensive but at the same time do not guarantee permanent safety.

The structural measures like embankments, dams and drainage channels rarely provide total protection against floods. Despite this, flood control measures have rarely gone beyond the construction of dams and embankments. Between 1954 and 1978, 10,821 kms. long embankment had been built. By March 1987, this figure had gone up to 14,511 kms. (see Table 7.4). Numerous rivers have had long stretches embanked on both banks. And despite all the warnings of the various committees, the rate of building over 400 kms. of embankments annually had been kept up since 1954.

By the mid-1970s, a north Bihar river like the Burhi Gandak had 317 kms. long embankments on its left bank and 312 kms. on its right bank; the Kosi had a total length of embankments of 246 kms. and the Bagmati had some 333 kms. By 1987, 4,448 kms. long embankments had been built in the Brahmaputra and the Barak valleys of Assam. Some 459 towns and 4,701 villages had been protected across the country and 28,036 kms. of drainage channels were constructed. Overall, a total area of 13.37 mha had been protected as compared to 9.99 mha in 1978 and about 3 mha when the British left. Meanwhile, the total expenditure on flood control increased from Rs 13.2 crore in the First plan (1951-56 to Rs 786.8 crore in the Sixth Plan (1980-85 and an outlay of Rs

947.4 crore in the Seventh Plan (1985-90). Flood control outlays have generally fluctuated between 0.64 and 1.08 per cent of the total five year plan outlay.

In addition, the Government has spent vast sums on constructing dams. By 1986, 256 large dams (with a height of 15 m and above) had been built, and 154 more were under construction. Only about 30 odd dams had been completed in the Indo-Gangetic and the Brahmaputra valleys, the most flood prone regions. Another 15-odd major dams were under construction in these areas. According to an extensive report on 'Non Structural Aspects of Flood Management in India' prepared by Indian National Committee on Irrigation and Drainage (INCID) in 1993, it was both technically and economically impossible to provide protection to all flood prone areas through structural measures due to resource constraints. The INCID document has stressed the need to keep people away from floods, and not try to keep flood waters away from people. Flood Plain Zoning (FPZ) being tried out in recent years was one sure way of minimizing flood damage.

Table 7.4 Length of embankments

States	Length of embankments		Area protected
	From 1954 to 1978 (kms.)	Up to March 1987 (kms.)	upto March 1987 (mha)
Andhra Pradesh	405	507	1.00
Assam	4145	4448	1.56
Bihar	2355	2756	1.87
Goa, Daman and Diu	7	9	-
Gujarat	208	408	0.43
Haryana	396	578	1.70
Himachal Pradesh	2	58	0.01
Jammu & Kashmir	-	56	0.06
Karnataka	-	-	Neg
Kerala	44	92	0.03
Madhya Pradesh	-	13	Neg

Maharashtra	26	26	Neg
Manipur	127	279	0.08
Meghalaya	45	106	0.09
Orissa	370	1007	0.46
Punjab	821	1047	2.66
Rajasthan	82	141	0.04
Sikkim	-	-	-
Tamil Nadu	-	35	0.08
Tripura	39	114	0.03
Uttar Pradesh	1174	1711	1.42
West Bengal	515	974	1.75
Delhi	60	83	0.08
Pondicherry	-	61	0.01
All India	10821 Seq.	14511	13.36

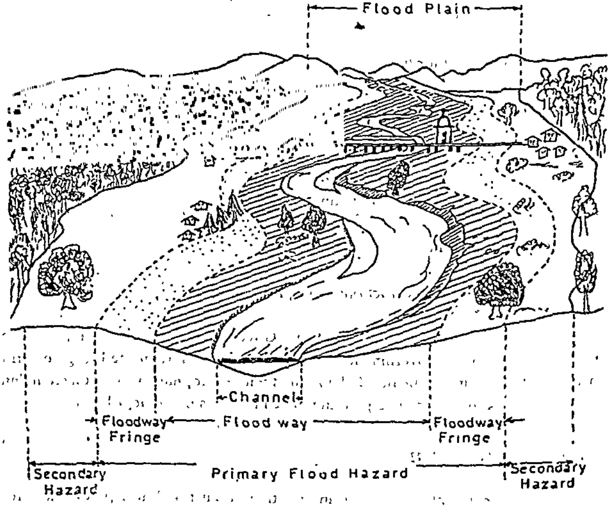
Note 1 Area protected by all measures, including drainage channels and protection of towns and villages.
Note. 2. An additional 6,000 kms. of embankments had been built before 1954 (RBA).

5. Flood plain zoning

FPZ requires information on flood plains, particularly the identification of floodways in relation to land use. In flood plain zoning, detailed maps of flood prone areas are prepared after studying flood cycles. Some areas are more prone to flooding and in some areas the frequency of flood is quite high. These zones are identified and demarcated and necessary control is exercised regarding land use (Fig 7.12).

Recourse is taken to legislative measures to restrict engineering, industrial and economic activities in these zones. These include not permitting construction of building or industrial units (if they are not at a desired level), acquisition of vulnerable land by the Government for developing it into a greenbelt, wildlife sanctuary, etc. Alternatively, the development right of flood prone areas are bought by the Government although the original owner may retain it as a farm but may not use it for residential or commercial purposes If any individual tries to develop this land, it will be without

Fig.7.12. A schematic diagram of flood plain zoning



any help from the Government and no civic services such as telephones, water and electricity supplies, insurance, etc. will be provided.

Recognising the importance of FPZ as an effective means of flood control, the Central Flood Control Board mooted the idea in 1957 to demarcate flood zones to prevent indiscriminate settlement in flood plains. In 1975 a model FPZ bill was circulated by the Centre to the States for an early enactment on these lines. The provisions of the bill were

(a) flood zoning authority;

(b) delineation of flood plain;

(c) notification of limits of flood plains;

(d) restrictions on use of flood plains;

(e) compensation; and

(f) power to remove constructions after prohibition.

However, the response from the State Governments, except Manipur, is not encouraging. The State Governments are being continually requested to give serious consideration of zoning of the flood plains and their development in a regulated manner through administrative measures pending enactment of suitable legislation.

6. Flood Forecasting

Regarding flood control, advance information about flood also plays a key role. Losses due to flood, especially of human life and livestock, can be considerably reduced by flood forecasting and early warning to the affected areas. Normally a flood peak takes a few hours to few days to pass from a point upstream to a point downstream along a river. So, if the water level is constantly monitored, it is possible to issue forecast of floods downstream well in advance for the local authorities to take precautionary steps to minimise the loss of life and property. Flood forecasting is the most effective way of flood management.

The Central Water Commission (CWC) is entrusted with the task of forecasting floods. It has a network of 157 forecast stations in 11 floodprone statesand 2 Union territories. Bihar has the largest number of flood forecasting stations. The network uses INSAT extensively for monitoring and transmitting data. In 1992, the accuracy of forecasts was 96%.

7. *Water Diversion*

The Government has also toyed with the idea of diverting excess water from flooded rivers to perennially drought hit areas. The national perspective for water resource development has envisaged linking of the Himalayan rivers to those in the Peninsular India: A National Water Development Agency was set up in 1982 for this purpose. The plan has proposed 36 river water transfer links. Preliminary studies on 12 of these have been completed. More programmes will be taken up in the 9th plan.

Bring water to Rainshadow regio of Sahyadri.

Flood Management Programme in India

The practice of building flood protection embankments along rivers was an ancient one in the Godavari, the Krishna and the Cauvery deltas and in the Indo-Gangetic plains. However, nationwide flood protection programmes began only after independence.

When the British left, there were some 5,280 kms. of embankments along different rivers, of which 3,500 kms. were in the Sundarbans in West Bengal and 1,209 kms. along the Mahanadi in Orissa, providing protection to a total of about 3 mha. Not enough attention had been paid to flood control measures by the colonial rulers. Committees were appointed from time to time in Assam (1929, 1934 and 1947), Bihar (1926) and West Bengal (1922), but their recommendations were rarely implemented. Investigations carried out by these committees also suffered from a shortage of information regarding the behaviour of rivers.

The First Plan which began in 1951, decided to move away from embankments and put more faith in large dams to store flood waters. The plan document stated that "the construction of large dams to store these flood waters is the most effective way of preventing flood damage." Dams were conceived on the flood prone rivers of the Damodar, the Mahanadi and the Kosi. But even before the plan was half over, the idea of dam on the Kosi at Barahshetra in Nepal had to be shelved. The Nepalese

Government remained lukewarm towards the project. The proposed site was also located too close to the epicentre of an earlier major earthquake. As a result, stress once again shifted to embankments, especially in north Bihar, while dams were constructed on the Damodar and the Mahanadi.

In 1954, came a spate of severe floods - one of the worst in the country. All northern rivers flooded simultaneously and led to enormous devastation across Uttar Pradesh, Bihar, West Bengal and Assam The severe floods attracted public attention to the inadequacy of flood control measures. After the unprecedented floods of 1954, flood management works were taken up in a planned manner by the State Governments. The main thrust of managing floods in different river basins was to modify the floods towards specific structural measures such as reservoirs, embankments, channel improvement, town protection and river training works. From 1951 to 1992, the main flood management works constructed are: (i) embankments 15,800 kms.; (ii) drainage improvement 32,000 kms ; and (iii) protection to 850 towns (Table 7.5). These measures have provided a reasonable degree of protection to an area of 11 million ha. The cost of these works is about Rs 31,500 millions. Though the expenditure on flood management works during the earlier plans was not much but the same was increased substantially during the Sixth and the Seventh Plan (1980-85 and 1985-90).

In spite of substantially increased outlays the flood damages continued to show increasing trend during the eighties (Table 7.6). The main reason for this as could be identified was heavy encroachment of and unregulated development in flood plains in floodprone States and 2 Union Territories

Table 7.5: Flood Management Works Executed up to March 1991

1	Embankment (km.)	15764
2	Drainage Channels (kms.)	31888
3	Twon Protected (Nos.)	857
4	Village Raised (Nos.)	4705
5	Area Benefited (M Ha.)	14.08

Table 7.6: Planwise Expenditure and Area benefited

Period	Total expenditure (Rs. million)	Area protected (M Ha.)	
		Plan	Cumulative
(1)	(2)	(3)	(4)
I Plan (1954-56)	132.1	1.00	1.00
II Plan (1956-61)	480.6	2.24	3.24
III Plan (1961-66)	820.9	2.19	5.43
Annual Plan (1966-69)	419.6	0.40	5.83
IV Plan (1969-74)	1620.4	2.21	8.04
V PlanÀd1974-78)	2986.0	1.94	9.98
Annual Plans (78-80)	3299.6	1.23	11.21
VI Plan (1980-85)	7868.5	1.80	13.01
VII Plan (1985-90)	9494.5	0.79	13.80
Annual Plan (90-91)	1978.8	0.28	14 08
During (1954-91)	29101.0		14.08

Table 7.7: Statewise detail of the funds allocated under state plan during 1993-94 and 1994-95, in Rs. Crore.

State	1993-94	1995-96
Andhra Pradesh	62.7	55.2
Bihar	27.0	44.7
West Bengal	15.0	36 0
Assam	15.0	19.8
Punjab	11.24	15.7
Kerala	13.0	15.0
Karnataka	10.0	12.1
Delhi	10.0	12.0

J & K	8.8	10.1
Haryana	8.9	9.1
Uttar Pradesh	9.0	8.0
Orissa	5.0	7.0
Rajasthan	5.8	7.0

Important Words

Bankfull condition
Drainage Channel
Water Harvesting
Drainage Congestion
Cloudbursts
Runoff
Channel Improvement
Flood Plain Zoning
Tidal Waves
Dugwells
Embankments

8

DROUGHT

Introduction

Drought refers to a situation when rainfall fails in general and the ground water water loses its potentiality affecting the biotic life adversely. Drought is a relative phenomenon in the sense that the amount of moisture available is not that important to life as its effectiveness.

Drought is basically a distress situation caused by lack of rainfall. The failure of rains may be reviewed from two aspects. Firstly, the rainfall may be insufficient, but secondly, it may be sufficient for the region as a whole but with a wide gap, separating two or more spells of rain. Thus the quantum as well as the time of the rainfall both are important. In other words, drought is a relative phenomenon. Therefore the amount of rainfall is not that important as is its effectiveness

Drought: Type and distribution

A distress situation caused by lack of water, falls in three categories of drought, depending on meteorological, hydrological and agricultural aspects. In general terms, we talk about **meteorological drought**. A meteorological drought is a situation when the actual rainfall is significantly less than the climatologically expected rainfall over a wide area. But all observed drought is not meteorological drought. There are, however other forms of drought known by three different names - hydrological drought, surface water drought, ground water water drought and agricultural or soil water drought. **Hydrological drought** is associated with the drying up of surface water such as rivers

streams, lakes and reservoirs, in which case it is known as **surface water drought** and fall in ground water levels, in which case it is known as **ground water drought. Hydrological drought** occurs when meteorological drought is sufficiently prolonged. **Agricultural drought** or **soil water drought** occurs when soils loose their effective moisture conserving capacity through a complex of diverse processes and consequently leads to land aridisation: Agricultural drought may not exist even when meteorological drought exists and vice-versa.

Meteorological drought

The special situation in which the rains do not arrive in time or in adequate quantity is called meteorological drought.

As has been pointed above it is the effectiveness of the rainfall rather than its quantity that is more important The average rainfall in India is 105 cm. and it is considered to be the largest anywhere in the world for the country of comparable size, but it fluctuates widely. It is either delayed or it ends earlier or in between there are long breaks or the rainfall is concentrated in just one part and is completely absent in another.

Various Governmental agencies have devised ways to delineate drought prone areas

On the basis of coefficient of variation

The coefficient of variation is measured thus

$$C = \frac{\textit{Standard-deviation}}{\textit{mean}} \times 100.$$

The coefficient of variation varies from 15 to 30 per cent in India. So there are areas of higher variability and areas of lower variability. Lower the variability higher is the reliability and vice versa.

The highly variable rainfall areas are Rajasthan, Gujarat and Kachchh where variability is from 50 to 80 percent. Other areas where the variability is from 30 to 50

percent include the interior of the Peninsula to lee of Sahayadris or Western Ghat (Fig 4.19).

The Indian Meteorological Department (IMD) approach

The Indian Meteorological Department uses two measures - the first describes rainfall conditions while the second represents drought severity Rainfall conditions are defined as follows:

Excess	+20 per cent or more of the average of 70-100 years
Normal	+19 per cent to -19 per cent of the average of 70-100 years
Deficient	-20 per cent to -59 per cent of the average of 70-100 years
Scanty	-60 per cent or less of the average of 70-100 years

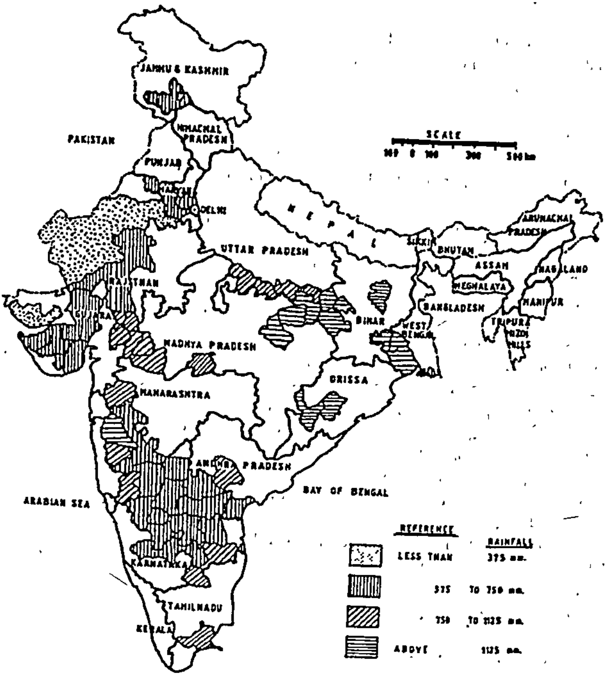
The precipitation is expressed on a weekly and monthly basis. Drought is described as moderate or severe if the seasonal rainfall (southwest monsoon) deficiency is 26-50 per cent or more than 50 per cent of the normal, respectively. The criteria used by the Indian Meteorological Department is the most accepted measure of drought, principally because of its simplicity Other measures of drought have been proposed. Subramanyam (1964), for example, defined drought intensities using standard deviation of the aridity index, while *Krishnan and Thanvi* (1971) used the aridity index of the Kharif (monsoon season) cropping season to describe the drought intensity. A drought prone area is defined as one in which the probability of a **drought year** is greater than 20 per cent A chronic drought prone area is one in which the probability of a drought year is greater than 40 per cent A drought year occurs when less than 75 per cent of the "normal" rainfall is received. Thus the drought area and the chronic drought affected areas are·

(a) Drought affected areas

1. Gujarat, Rajasthan and adjoining parts of the Punjab, Haryana, west Uttar Pradesh and west Madhya Pradesh.

   Madhya Maharashtra, interior Karnataka, Rayalseema, south Telangana and parts of Tamil Nadu.

Fig.8.1. Drought prone areas of India



3. Small portion of north-west Bihar and adjoining east Uttar Pradesh, south-west Bihar including Palamau and Garhwa district.

4. Small portion of north-east Bihar and adjoining portion of West Bengal.

(b) Chronically drought affected areas.

This includes western part of Rajasthan and Kachchh.

Thus the three drought areas (Fig 8.2) are:

(1) The track comprising the desert and semi-arid region of India in a rectangular form running from Ahmedabad to Kanpur and from Kanpur to Jalandhar comprising an area of about 0.6 million sq. km.

(2) The track comprising the regions lying in the lee of Sahayadris comprising an area of about 0.37 million sq. km.

(3) Pockets of drought which comprises Thirunelveli and Coimbatore districts of Tamil Nadu, Saurashtra and Kachchh region, Purulia district of West Bengal and Kalahandi region of Orissa comprising 0.1 million sq. km. Thus the total area affected by inadequate rainfall is over 1 million sq. km.

The rainfall criterion described above is useful for a continuous monitoring of the monsoon season. The sum of the season's rainfall becomes the basis for describing a region under moderate or severe drought. When more than 50 per cent of the area in the country is under moderate or severe drought, the country is described as severely affected by drought; and when the affected area is 26-50 per cent of the country, it is described as an incidence of moderate drought.

It is seen that most of the areas susceptible to drought fall between arid and semi-arid zones of the country and chronically affected drought areas are identified with extreme arid conditions. However, droughts may occur outside this zone in areas like Vindhyan Maharashtra, Chhattisgarh in Madhya Pradesh and some areas in the east in subhumid regions.

There are six major causes of drought as far as rainfall is concerned

(1) Late onset and early withdrawal of monsoons

(2) Lean rainfall due to absence of depressions (low pressure system) passing over India

(3) Prolonged breaks in monsoon rainfall

(4) Re-establishment of southern branch of jet stream

(5) Upwelling of cool water over the Arabian Sea and extension of cool Somali currents over the Arabian Sea

(6) The movement of monsoon trough closer to the Himalayan zone (*see Chapter-2, Climate*).

It is not known clearly as to what causes late onset and early withdrawal. The physical mechanism which leads to this meteorological situation is not fully understood. With more information on cloud structure in the near future, the conditions that leads to the late or an early onset of monsoon can be known.

The absence of depressions and low pressure systems passing over India is actually associated with the global weather systems. The **southern oscillation** is one such meteorological system that affects the generation of these depressions. The low pressure system which dominates the area around Tahiti in central Pacific and associated high pressure over Indonesian and southeast region naturally prevents the formation of cyclones (*see Chapter-2, Origin and Mechanism of Indian Monsoons*) and depressions over Indonesia and the Bay of Bengal.

The prolonged breaks in monsoon rainfall is again part of the global weather dynamics Past rainfall data suggests that prolonged breaks in monsoon rainfalls have a tendency to occur towards the second half of the season that is in August and September. This type of phenomena occurred in 1974, in 1979 and in 1981 These breaks are linked with **quasi-stationary anticyclonic** (see *Chapter-2, Origin and Mechanism of Indian monsoon*) circulation that establishes itself over north-west India. This anticyclonic circulation inhibits the upward motion of air suppressing rainfall generating condition. Again how meteorological features influence this type of circulation is not fully understood.

The re-establishment of the southern branch of Jet stream is also a part of the global weather dynamics which cannot be fully explained. The effect of re-establishment of jet stream is the suppression of convection. Suppressed convection inhibits cloud formation and consequently rainfall.

The upwelling phenomenon over the Arabian Sea caused due to pushing of cool Somali current decreases the sea water temperature by as much as 2 to 4 degrees. The low surface water temperature decreases evaporation and consequently the moisture content of the wind. With a lowered moisture content, the amount of rainfall all along the western coastal belt and in the lee of Sahayadris is also lowered

Rainfall along the axis of the monsoon trough is heavy because the trough is the passage ways of smaller depressions Thus when the monsoon trough lies close to the Himalayas there is abnormally heavy precipitation in the foothills This causes floods while the rest of plain goes dry inviting drought.

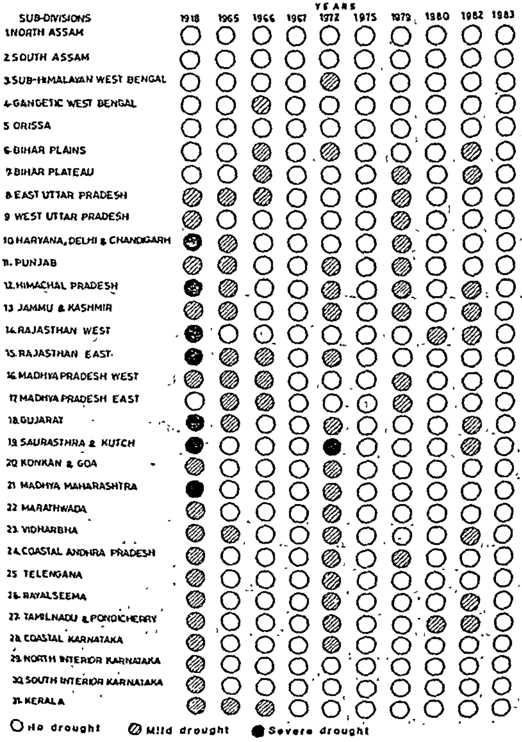
THE PALAMAU DROUGHT

Amazing but nevertheless true, is the fact that in the last 135 years, Palamau has witnessed nearly 35 years of drought in which countless people starved and cattle died. The region was hit by droughts in 1859-60, 1873-74, 1896-97, 1899-1900, 1918-19, in almost the entire decade of the 1980s - the most severe being in 1989 and 1992.

Several factors are attributed to the recurrent droughts in central and south western parts of Bihar. First, Palamau falls under the retreating range of the south west monsoon and the rainfall is wholly dependent on the local winds which are seldom favourable. Secondly, the region has several rain-fed rivers emanating from the Chhotanagpur plateau in South Bihar. Most of them end up in the plains of central Bihar and a couple of them manage to reach the Ganga. This is in total contrast to the snow- fed rivers of north Bihar.- most of them originating from the Himalayas and falling in the Ganga. So, if Trans-Ganga north Bihar is hit by floods, the hilly and arid south western districts are plagued by drought. Thirdly the region falls in a rain shadow area.

Lastly, the geological and lithological set up does not permit setting and charging of acquifers. Consequently, the ground water table is low.

Fig. 8.2. Incidence and intensity of drought in India



If lack of water were the sole criteria for the definition of drought, then the areas receiving heavy rainfall such as North- Eastern India and the Western Ghat regions had no business to be drought affected. But drought like conditions do exist in these places during March-April. It must be recognised that climatic and rainfall variability is intrinsic part of tropical meteorology. India's weather conditions like many part of tropical world is characterised by short term fluctuations which is not adequately explained. When the monsoons appear over India, depressions and cyclonic disturbances can cause appreciable spatial variations in rainfall. At the same time these disturbances do not give a common pattern. For example, during 1917 and 1918 monsoon season the number of disturbances were equal while 1917 and 1918 are the wettest and driest season of India, respectively, during the period 1901 to 1960.

Droughts resulting from failure of rainfall is a product of meteorological variability Such variabilities had been an intrinsic part of India's weather condition and can hardly be avoided. Droughts are bound to reoccur because they are, afterall, a part of tropical meteorology. Except for small pockets of north-east there is no area in India that has not been affected by drought at one time or the other (see Table 8.1). For every seven good seasons there are at least two or three bad seasons in India

Table 8.1: Probability of Occurrence of Drought in Drought-Prone Meteorological Subdivisions

Source S K Sinha, K Kailashnathan and A K Vasistha

Meteorological Subdivisions	Frequency of Deficient Rainfall (75% of normal or less)
Assam, Northeast Region	Very rare, once in 15 years
West Bengal, West Madhya Pradesh, Konkan, Coastal Andhra Pradesh, Maharashtra, Kerala, Bihar, Orissa	Once in five years
South interior Karnataka, Eastern Uttar Pradesh, Vidarbha, Gujarat, Eastern Rajasthan, Western Uttar Pradesh	Once in four years
Tamil Nadu, Kashmir	Once in three years
Rayalseema, Telangana, Western Rajasthan	Twice in five years

A meteorological drought sees a transition to hydrological drought and then on to agricultural drought in a slow process Often it takes two successive meteorological

drought before the hydrological drought sets in. And then it slowly leads to agricultural drought But the various forms of hydrological drought and agricultural drought may not always be the reflections of meteorological droughts.

India's water scarcity are more related to problems of managing water resources following precipitation. This is borne out by the fact that even if there is no meteorological drought, drought like conditions occur. In fact, in acute drought affected regions like Rayalseema rainfall data studies since 1945 have indicated that no meteorological drought has occurred there.

In fact, water scarcity and drought exist whenever the links in water cycle are broken or established While the various forms of drought can be generated independently, it would, however, be wrong to say that rainwater, surface water, soil water and ground water are ecologically disconnected. These systems are inseparable and are linked to each other through the wave cycle that describes the dynamics of continuously moving water resource Except the geological water trapped in deep aquifers, all other water forms are ecologically linked to each other.

Hydrological drought

Hydrological drought comprises surface water drought and ground water drought.

Surface water drought

Apart from meteorological drought there are many other processes through which water scarcity gets generated. Deforestation and hydrological destabilisation in the mountain catchment of rivers can make rivers and streams dry up in the post monsoon period. In such a situation surface water drought occurs even though the rainfall is normal. This has happened in Cherrapunji where it has become normal. With the destruction of hydrological capacity of the mixed natural forests in the catchment, the entire 450 inches (1200 cm) of rainfall instantly runs off and as soon as monsoon is over the springs and the streams start drying up and water scarcity sets in one of the wettest spot of the earth, during March- April. This creation of surface water drought through degradation of the catchment is the result of failure in maintaining the ecological processes which allow the rainfall to infiltrate and to percolate underground to be discharged as perennial sources. The destruction of the infiltration path of the

water cycle under tropical conditions, where rainfall is seasonal immediately creates flood after the rains and water scarcity in the rest of the year.

Surface water drought also results from conversion of catchment forest into monoculture plantation of commercial species like pine or eucalyptus These trees do not provide adequate defence to the soil against the direct hit of the raindrops during intense storms and thus enhances the prospects of flash floods and consequently, the surface water drought occurs. This has happened in the Terai region of Uttar Pradesh

In the arid and semi-arid areas of the country planting of eucalyptus trees have led to destruction of water resources through heavy demand of evapo-transpiration

There are other important factors which have contributed to in the enhancement of flood/drought combined, such as ecologically hazardous mining, indiscriminate road construction, overgrazing, and growth of non-terraced agriculture In the Doon valley limestone quarrying has drastically changed the surface water flow in the valley turning many perennial rivers into carriers of monsoon floods which go dry after the monsoon.

All these factors have been contributing to hydrological instability. The cumulative impact of which is seen in worsening floods and droughts even under normal rainfall conditions. Flood- prone areas have been increased in the background of continuous drought situation.

Ground-Water drought

The lowering of the ground water table as a result of excessive pumping without a compensatory replenishment creates an almost irreversible ground water drought even in normal rainfall conditions. Except in the alluvial areas of the Indo- Gangetic plain, the rest of the country especially in the Peninsula has very limited ground-water potential due to existence of hard crystalline rocks.

Most of the ground water that is utilised in India comes from the shallow aquifer zone with depth less than 400 to 500 feet. To encourage irrigation, in the arid and semi-arid areas, pumps have been liberally installed ignoring the close hydrological link that exists between local surface water sources, the dug wells and the shallow aquifer bore-wells. Accordingly, while drought is getting mitigated for the cash crop growing farmer, energised pumpsets are creating new drought for the marginal and

poor peasants by lowering the watertable below their reach, where it can be effectively utilised This has really become an acute problem in the hard rock areas of Maharashtra, Karnataka, Andhra Pradesh, etc

Indiscriminate exploitation of ground water facilitated by rural electrification and installation of pumpsets during droug..t have itself created ground water water drought. This process has been so indiscriminate that it has seriously depleted the underground water resources in some parts of the country Over pumping has resulted in a permanent lowering of the ground water table making ground water utilisation ultimately uneconomic

(6) Uncontrolled expansion of eucalyptus plantations which have a high water demand, and an unscientific use of groundwater for irrigated cash crops like grapes, vegetables, flowers, etc have resulted in a total ground water water drought. This has happened in Kolar and other semi arid areas of the country.

The filling up of several *abars* ponds and tanks for the purpose of road construction and 'beautification' has also led to a very adverse effect on the ground water water table, because these ahrs served as recharge point for many fragile acquifers.

At present drought is more permanent and pervasive in most parts of the Peninsular areas because of the drop in the water table Dug- wells and tanks also do not share water for very long as shallow aquifers are totally exhausted creating a pseudo drought condition The intensification of **pseudo drought** is ostensibly due to encouragement given to ground water water based irrigation, sometimes with the declared objective of drought relief.

Agricultural drought

When soil moisture and rainfall conditions are not adequate enough to support a healthy crop-growth to maturity during growing season thereby causing **extreme moisture stress** and wilting of major crops area, it leads to a drought situation called **gricultural drought.** Agricultural drought may exist even when meteorological rought may not occur and vice-versa. However, agricultural drought or soil-water ought is a relative category, dependent on the nature of plant and soil. What could a drought condition for paddy could well be condition of excess soil moisture for crops like bajra or jowar. Thus the choice of crops evolve according to the variations

of climatological and soil conditions. The indigenous dry-crops prove very high yielding when water- use is optimised. However, under extreme condition of soil water drought, no plant would be able to survive and this condition is described as desertification.

Table 8.2: Water demands of different crops and productivity

Crop	Water (in mm)	Productivity (kg/ha)
Rice	950	1.72
Ragi	250	4.65
Jowar	250	4.47
Sugarcane	1250	-
Wheat	400	-
Maize	200	-

...green revolution agriculture has created a largely ... of increasing food- production in limited areas where irrigation is available. This agriculture is so precariously dependent on irrigation water that any delay in supply of water, because of actual water scarcity or due to mismanaged distribution, will cause serious soil-water drought. On the whole green-revolution agriculture has increased its vulnerability to drought in many ways. Intensive green-revolution agriculture has contributed to drought in another way, that is, by large scale use of pesticides. 22

An Introduction of HYV's and consequent replacement of traditional drought resistant varieties has been another factor contributing to agricultural drought. HYV's demand more water and that too, in specified intervals. Besides, the organic matter content of HYV's is also quiet less. Organic matter input to the soil increases its water holding capacity and hence soils rich in organic content don't dry quickly. The HYV's with their low organic matter content are thus liable to cause soil water drought. It has been observed that with the addition of manure and organic fertilizer, the water retentivity in the soil increases by 2 to 5 times and the evaporation increases by 15 to 20 percent. The decreased organic matter production destroys the only effective means of drought control in drought prone areas where organic matter addition to the soil is a significant measure for water-conservation. Large doses of organic matter have

traditionally been added to the the soil in the Deccan which helped retention of moisture but with the introduction of HYV's it has been taken away.

Similarly, the change in cropping pattern has also led to soil water drought. The indigenous cropping pattern was in equilibrium with the agroclimatic condition of the region, *but with the introduction of an alien cropping pattern* with more water demanding crops, soil water drought sets in. This has been the case in green revolution affected areas comprising Punjab, Haryana and western Uttar Pradesh.

Disproportionate allocation of water to cash crops in the dry land areas has also created soil water drought Thus, while the staple-crops in drought affected areas of Maharashtra, Karnataka, Andhra Pradesh, are denied water, sugarcane fields or grape-vines are frequently irrigated. In this way, a *soil water drought is created* not by absolute scarcity of water but preferential diversion of limited sources of water.

Interrelations of drought phenomena

Although all these three forms of drought can occur independently, the occurrence *of* [illegible] *hydrological and agricultural* dr[illegible] hydrological drought and may, thereafter, lead to agricultural drought. Although an agricultural drought may exist even when meteorological drought may not occur and vice-versa.

The transition from meteorological drought to hydrological drought and from that to agricultural drought is a slow process. It may take two successive meteorological droughts *for hydrological drought to occur and then it slowly leads to agricultural* drought.

Drought has both spatial and temporal dimension It may be a local phenomenon confined to a region of a country or it may envelope a much larger part of a country. Drought may occur over one or two season or even more. By 1987, Rajasthan has suffered from four successive droughts and Gujarat from three successive droughts.

While no regular drought cycle can be established, conditions of drought do occur [illegible]

[illegible] *occurrence of drought is complicated in both time and space. Pockets such as Kalahandi*

in Orissa, Palamau in Bihar may experience perpetual drought along with some portions of Rajasthan, Gujarat and interior Peninsula. While some regions experience drought in one part of the year, i.e., during non monsoonal time, others may experience drought whenever a change takes place and wherever it has taken place because of change in agricultural practices and pattern in the region.

"Agricultural drought is not the end, it is the beginning of a slow and sure process by which it permeates through the economy and makes its impact on the ordinary lives of the mass of people" (*Dubashi, 1993*).

Impact of drought

Drought has manifold impact on the geography of a country. The impact can be studied under various heads.

Physical Impact

[illegible] effect on the recharge of soil moisture, [illegible] the water table is lowered and the surface runoff is reduced to lowering the reservoir levels. In absence of recharge, the water table is lowered causing the wells to dry up. The drying up of wells has an adverse effect on irrigation. A meteorological drought also causes the runoff to decrease causing the rivers to dry up during the dry season. This also has an effect on the lowering of the reservoir water level.

Impact on Agriculture

Indian agriculture is still largely monsoon controlled, dependent on environmental factors such as rainfall, ground water water condition and soil moisture condition. Thus it is largely prone to meteorological, hydrological and agricultural drought. The effect is manifested in the shortfalls of agricultural production in drought years. The major drought of 1918, 1965, 1966, 1972, 1979 and 1982 caused losses in foodgrain production (Table 8 3). An important aspect of production is that despite drought, an upward trend in grain production has been maintained and the import of food has been eliminated. The food production has, however, been quite fluctuating. In 1978-79 a peak was reached with 131.4 million tonnes of food grains was reached followed by 109 million

tonnes (a 17 per cent decrease) production in the drought year of 1979. In 1980-81 and 1981-82 foodgrain production reached 129.5 and 133.3 million tonnes respectively. The drought of 82-83, however, caused a reduction of only 5 million tonnes or 3.7 per cent over the peak production period of 1981-82

Table 8.3: Extent and impact of drought in important drought years

Drought Year	% of the Country Affected	% Reduction in Food Grain Production over the Previous Peak Year	Total Food Grain Production (in million metric tonnes)	Import of Food Grains (in million metric tonnes)
1918-19	73	32.3		
1965-66	54	18.8	72.4	10.6
1972-73	43	7.7	97.0	3.6
1979-80	41	17.0	109.0	0
1982-83	37	3.7	128.4	0

A shortfall in production may be the direct impact of meteorological drought but consecutive meteorological droughts, hydrological and agricultural droughts have a long range and far reaching impact on agriculture. This impact may be in the form of changes in cropping patterns and impoverishment in cattle. 1

Social and Economic Impact

economic problem

Drought has far reaching socio-economic impact. In India, drought has often led to famine type conditions. Of course, drought is often not the cause of famine but there is a striking coincidence of drought years with occurrence of famines. A bad harvest following drought leads to a reduction in the purchasing power. A lowered purchasing power in fact is the reason behind famines.

There is a sequential pattern in which the impact of the drought manifests itself. The consequences are:

(1) Decline in crop acreage.

geographical problem

(2) Set back to agricultural production (crop production, milk production).

(3) Fall in employment in the agricultural sector due to slowing down of agricultural activity.

(4) Fall in purchasing power of those engaged in agriculture

(5) Scarcity of drinking water; fall in water-table.

(6) Scarcity of foodgrains.

(7) Rise in the price of foodgrain and other commodities.

(8) Scarcity of fodder.

(9) Distress sale of cattle.

(10) Loss of cattle life.

(11) Low intake of food.

(12) Malnutrition specially among children.

(13) Ill health and spread of diseases like diarrhoea, dysentery or cholera-famine and opthalmia caused by starvation.

(14) Distress sale and mortgage of land, jewellery and personal property.

(15) Migration of people in search of employment, depopulation of area

Very Impt.

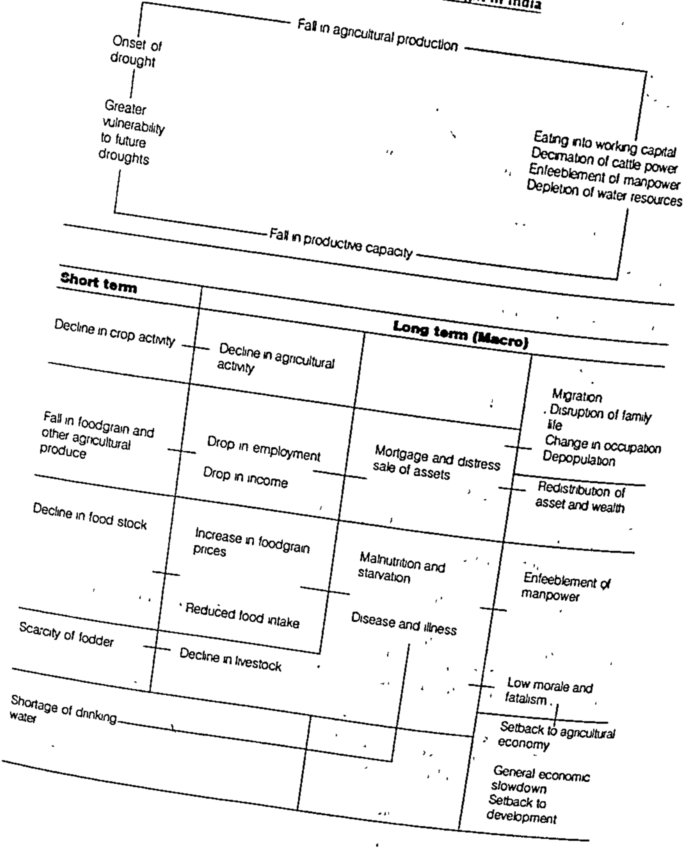
(16) Death due to malnutrition/starvation/diseases.

(17) Fall in effective demand from agriculture sector leading to dislocation of productive processes and slowing down of the economic activities in the secondary and tertiary sectors. (in rural areas as well as urban areas)

(18) Low morale of people.

First Finance

Fig.8.3. Consequences of drought in India



(19) Social stress and tension, disruption of social institutions and relationships and social crimes, e. g , looting of grain shops.

(20) Growth of fatalism, reliance on heavenly powers

Droughts do affect the social and economic life of people, but the severity of the impact depends on :

(1) The manner in which it is tackled

(2) The stability, strength and resilience of the economy of the society.

The impact is greatest on the most vulnerable sections of the society who have a hand to mouth economy and very little margin and **staying power**. These include the landless and marginal farmers, the artisans like the weavers whose very existence depends on local demand. These people do not have anything like stock and even if they have, once these stocks are exhausted they are compelled to sell or mortgage their belongings to the richer people. A series of bad harvest plunges the small and marginal farmers in a vicious circle of poverty making them landless and penniless.

On the contrary the richer sections emerge more stronger. They take advantages of scarcity and high prices of food to make a fortune out of their surplus stock In the extreme condition they exploit the weakened economic position of these marginal farmers and their inability to repay the loan forfeiting their mortgage. Thus after a drought the rich becomes richer and the poor, poorer.

Although the drought is short term phenomena, its impact is felt over a much longer period. Its adverse impact is felt widely in the form of depletion of underground water resources, lowering water table, death of human, animal alike, etc., and these are greatly aggravated by the cumulative impact of successive droughts. This happens only if the drought is severe. A mild drought followed by a good season may not leave its marks.

Severe drought followed by moderately good season leads to a secular decline of the economy. On the contrary, a mild drought followed by good seasons and effective handling of the consequences may not come in the way of secular upward movement of the economy.

In the long term, some consequences of drought may be easily overcome, but most of them leave a permanent imprint on the economy. When a drought is followed by a good rain, it leads to an increased fodder production, replenishment of depleted food stocks and may also increase opportunities of gainful employment. Some changes, however, are irreversible and more lasting. These changes include redistribution of assets and wealth and may create inequalities which go on accentuating in the coming years as marginal farmers become landless farmers and emigration, depopulation and run- down infrastructure turns the region into a depressed or backward area which neither manpower nor capital nor enterprises can cure. These processes are irreversible and get entrenched in the shape of structural changes in the rural economy and society. Drought may also lead to famines but this is not always true.

Management of Drought

Drought can be managed in two ways

(1) Preventing the causative aspects of drought.

(2) Providing relief to victims of drought and also rehabilitating them.

The reoccurrence of drought can be prevented by eliminating the causes which are responsible for it.

Management of Meteorological Drought

Meteorological drought will be a part and parcel of India's climatic conditions as long as India is in the tropical realm. The complexity of meteorological phenomena on such as re-establishment of Jet stream, movement of monsoonal trough close to the Himalayas, el NIÑO effects and global pressure changes (**Walker's Circulation**), the upwelling phenomena in Arabian sea, etc , cannot be managed as they are part of a complex atmospheric circulation.

To an extent, the meteorological drought can be managed by predicting the variability of changing weather. The predictions to lessen the impact of climatic variations. Thus weather forecasting can be thought of as one of the most important tools for this purpose. A prediction that the rainfall will be less than the normal will help the farmer to judiciously choose crops that are less water demanding. If on the

other hand, a water demanding crop is grown in the absence of current information about rainfalls an artificial drought condition may occur.

Management of hydrological drought

In so far as hydrological drought is concerned which is readily manmade, management can be done through various techniques and methods.

Hydrological drought management aims at preventing the drying up of surface streams and checking the fall in ground water table. This can be done by

(a) Biological Methods

(b) Engineering Methods

(c) Involving local people.

Biological Methods

Biological methods involve taking help of vegetation, i. e. bringing about overall change either in the type of tree grown or overall planning in integrated manner

(1) Checking indiscriminate deforestation growing apace in the hilly region. A deforested region decreases percolation (thus lowers the ground water water table) and increases run-off and flood incidence.

(2) Treatment of watershed by planting suitable trees under **social forestry** and **farm forestry**. It should be an integral part of watershed management. This will reduce the prospect of flooding in the lower portion and consequently surface water drought and at the same time, recharge the aquifers through its input into the intake basins.

(3) Converting monoculture plantations of pine or eucalyptus by ecologically suitable trees which provide adequate defence to the soil against the direct hit of raindrops during intense storm. This will reduce the prospects of flash flood and thereby prevent surface water drought This method will be particularly effective in the lower Himalayan region. In addition, monoculture eucalyptus plantation which

drains a large amount of water through its enormous evapo-transpiration capabilities should be replaced by trees which provide not only economic security but also ecologic security to the people. This will also help in raising the water table and tiding over artificial ground water water drought.

Engineering Methods

Engineering methods involve artificial recharge of ground water by different *methods*

Aquifer recharge

In the mountainous terrain, the most effective and appropriate way of recharging ground water is to cover the watershed with thick vegetation - multistoried forests with trees, shrubs and grasses and thick carpet of litter. This will allow greater infiltration of rainwater. But in flatter terrains ground water can be recharged artificially in addition to putting the ground under forest cover. This can be done by allowing the flood water to spread on the fields and fill the excavated trenches, tanks, ditches and furrows on the sides of the roads and railway lines. The stored water will eventually find its way to underground reserve. Spreading of flood waters on crop fields such as of paddy would greatly augment the ground water reserve. The stored water, behind the dam, serves very much the same purpose. In semi-arid region constructing embankments at suitable interval across seasonal streams also recharges ground water water

Another way of artificial recharge is injecting water through wells in areas where excessive water has been withdrawn such as the southern and central parts of Mehsana district of Gujarat. This method, to a large extent, will help to reverse the "irreversible" drop in water table. These type of efforts have been made in the Ghaggar basin at Kurukshetra and near Ahmedabad where water from the Sabarmati river was injected through syphon- pumps. In the Peninsular regions the traditional tank system cause one such mechanism to recharge ground water, by increasing percolation from surface storage of rain water. But since colonial periods there has been decay of tanks. Thus side by side with major irrigation projects, minor irrigation works like construction of small tanks must be paid immediate attention.

Diversion and storage of excess water

Diverting water from a water surplus region to water scarce and drought prone areas will considerably abate the distress situation. Thus interbasin transfer of water should be restored too. A model of this sort has been put forward by Mr. K. L Rao Rajasthan Canal Project has also basically done the same thing - it has brought the water of the Himalayan river to the chronically thirsty lands of Jaisalmer-Bikaner division in the desert; The Yamuna canal likewise transfers waters from the Ganga basin to irrigate a vast tract of dry Ghaggar basin in Haryana and adjoining Rajasthan. The National Water Policy (1987) has interbasin transfer of water as the main plank.

Involving local people

The involvement of local people and the mobilisation of the energy for water conservation does not have to wait for plans and projects formulated by Govt. department. The people if given leadership of an organisation could themselves undertake such projects despite unwillingness of administration to initiate them. There are many examples of this type of mass action in India such as the one by *Mukti Sangharsh Bahini* in Sangli district of Maharashtra where the people through *Shramdan* (donation of labour) constructed a small dam across a dry river Another action of this sort took place in Kolar district of Karnataka, Ralegansiddhi village in Maharashtra, Gogunda plateau in the heart of the Aravalli, etc.

Even the success of watershed development plans would depend on the involvement of local communities and mobilisation of social energy. It is only by mass awareness that over pumping and indiscriminate utilisation of ground water water can be checked.

Management of Agricultural Drought

The choice of crops in India has evolved according to the variations of climate and soil conditions. These conditions are diverse and as a response to this diverse requirement of soil crop combination, land and water use has evolved indigenously in India. It is in this perspective of the built-in resilience of indigenous practices and the

in the wheat monoculture region of the Punjab, Haryana and Uttar Pradesh. Thus the

towards pests, diseases, crop failure,

first task is to resort to the original cropping pattern suitable to that agroclimatic region. The native crops are not only less water demanding but the indigenous mix also helps to check the nutrient deficiency in the soil. Alternatively, stress should be put on drought resistant varieties and crops like sorghum, pearl millet, sunflower in drought prone areas.

Tree crops have a distinct advantage over agricultural crops in moisture deficient drought areas. Whatever be the cropping pattern the idea is to grow crops that are suited to that climatic conditions particularly in terms of their water requirement and not those crops which are more water demanding and create an artificial drought condition. In areas such as semi-arid zones of Maharashtra, Karnataka and Andhra Pradesh where scarce water resources are diverted to sugarcane fields and grapevine creating absolute scarcity of water for their staple crops, every effort should be made to stop preferential diversion and disproportionate allocation of limited irrigation water to cash crop.

Post Drought Management

The impact of drought can be mitigated by providing relief and rehabilitation. The Government has launched the Drought Prone Area Programme with a view to mitigate the effects of drought.

Drought Prone Area Programme (DPAP)

The precursor of the Drought Prone Area Programme (DPAP) was the Rural Works Programe (RWP) initiated at the beginning of the country's Fourth Five Year Plan. This was based on the decision that much of the amount, the Central Government spent on relief in famine affected areas could be so deployed in the areas of chronically affected by the drought as to generate considerable employment in the rural sector largely related to a pre-planned programme of rural works, Soon after the implementation of the RWP, it was realised that mere rural works would not be meaningful in bringing about drought mitigation and needed to be given area development approach. As a part of the mid term appraisal of the Fourth Plan, the RWP was redesigned as DPAP and funding on this basis commenced from 1972-73. After a number of reviews presently the DPAP cover 415 blocks in 95 districts of the country. The **Minhas Committee**, constituted by the Planning Commission had recommended that DPAP should aim at integrated development of agriculture with focus on restoration of

ecological balance. Apart from irrigation, forestry, soil and moisture conservation, it recommended changes i agronomic practices, restructuring of cropping pattern, livestock development, rural communication and drinking water supply as important elements of the strategy of integrated rural development Later in 1980, the entire programme was reviewed by a Task Force under the Chairmanship of M S Swaminathan, the then Member (Agriculture), Planning Commission. The Task Force redefined the scope and objective of DPAP and DDP. While reiterating the ongoing approach and strategy, it emphasised on:

(a) Promoting a more productive dryland agriculture on the basis of the soil-water-climate resources of the area;

(b) Development and productive use of the water resources of the area,

(c) Soil and moisture conservation, including promotion of proper landuse practices;

(d) Afforestation, including farm forestry; and

(e) Livestock development, including development pasture and fodder resources

Desert Development Programme (DDP)

The DDP launched in 1977-78, covering presently 131 blocks in 21 districts, was also to have a similar approach with accent on control of desertification

Since then, these programmes have been subjected to further review. The general feeling has been that in their attempt at drought proofing, the programmes have not been spectacularly successful. The contributing factors being non integration of different activities to the core objectives and low investment in a widely dispersed area In 1987, the Central Sanctioning Committee sought to sharpen the focus by limiting the programme activities to the core sectors of soil conservation, water resource conservation, afforestation and pasture development. It was decided at least 75 per cent of the annual allocation should be in respect of these activities. Further, it was also concluded that the unit of planning and development should be the micro watersheds. DPAP is funded by the Central and State Governments on matching basis.

In all, the following suggestions can be given for drought mitigation

1. Drought prone areas should incorporate short term and long term development projects such as fodder bank, pasture development/rangeland management as disaster mitigation practice.

2. An area specific watershed model development plan should be prepared for arid, Semi-arid and subhumid regions of the country.

3. In rainfed agricultural zones (having less rainfall and frequent droughts), considerable stress should be placed on development of khadi and village industries/cottage and handicrafts industries projects to provide gainful employment to the local people and check people's migration towards cities.

4. The development programmes such as National Watershed Development Programme for rainfed areas, DPAP, Desert Development Programme, National Rural Employment Programme, Drinking Water Programme and Poverty Alleviation Programmes should be integrated to form a comprehensive Drought Mitigation Programme.

5. Public participation and use of traditional practices for Disaster Mitigation should be given proper attention

Important Words

Meteorological Drought	**Hydrological Drought**	**Surface water Drought**
Ground Water Drought	**Soil Water Drought**	**Agricultural Drought**
Drought Year	**Southern Oscillation**	**Quasi-Stationary**
Secular Variations	**Moisture Sress**	**Pseudo Drought**
Staying Power	**Walker Circulation**	**Social Forestry**
DPAP	**DDP**	**Aquifer Recharge**

9

LAND CAPABILITY

full chapter To do [Sir]

Introduction

For any agricultural land development programme covering different areas, the first need is to prepare the basic planning documents. The land capability classification map is one such basic document for this purpose. It is particularly suitable for agricultural planning as it gives direct information regarding the soil potentialities of different areas This documents can best be prepared with the help of land capability survey.

Land capability classification

Land capability classification is a systematic arrangement of different kinds of land according to those properties that determine the ability of the land to produce crop on a virtually permanent basis

These properties are

(1) The inherent soil characteristics such as the texture of the top soil, its effective depth and permeability of the top soil and subsoil.

(2) The external land features such as the slope of the land, the extent of erosion the degree of wetness and susceptibility to overflowing and flooding.

(3) The environmental factor such as extreme aridity that limit the use of land.

The capability classification provides three major categories of soil groupings

1. **Capability unit**

2. **Capability sub classes** , and

3. **Capability class.**

1. Capability unit

Capability is a grouping of soils that have about the same response to yields, systems of management of common cultivated crops and pasture plants. This is the smallest category of land capability classification system and consider long term estimated yields which should not vary more than about 25% in one land capability unit.

2. Capability sub class

The **capability sub class** is a grouping of capability units, having similar kinds of limitations and hazards. The four general kinds of hazards and limitations are

(i) Erosion and runoff (including risk of erosion and post erosion damage).

(ii) Excess of water (wetness, high water table, problem of drainage, overflow)

(iii) Root Zone limitations, shallow depth, low water holding capacity salinity or alkalinity.

(iv) Climatic limitations.

Capability class

The **capability classes** take into account various criteria, among which potential productivity is the most important. The capability classes fall in eight categories

. Category I-IV suitable for cultivation

Category V-VII suitable for pasture and forestry

Category VIII suitable for wildlife and forestry

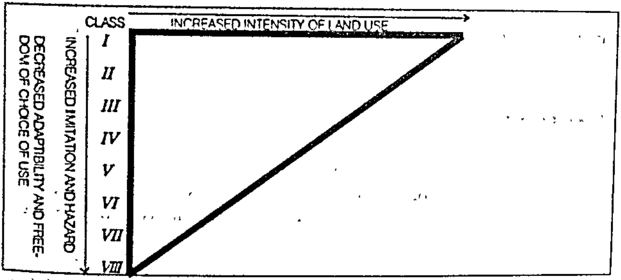


Fig.9.1 The Land Capability Classification

Significance

Land capability classification is a scientific appraisal of the physical characteristics of the land, its inherent soil qualities and the farm management practices. Thus, a survey of land capability maps based on regional unit delineate problematic and potential arable lands responsive to the use of biochemical techniques and to varying degrees of farm management practices. This has enormous practical utility as a rational land utilisation and cropping pattern can be developed which is consistent with the changing farm technology and crop adaptibility to the plant environment. Thus specific cropping patterns with their input requirement under rainfed and irrigated conditions can be efficiently planned. Similarly the priority areas for soil and water conservation, land reclamation and cropping sequence which can also be followed can be identified.

The classification is intended primarily as a means of determining the steps to control soil erosion hence capability classes mainly reflect the extent and complexity of conservation problems. It has attached an exaggerated importance to slope, while other qualities of soils indicative of soil fertility have been neglected. In its latest version *this classification has gone beyond the consideration of soil conservation. As such,* in a way, becomes more a classification of limitations.

Indian case

In India, as in many other countries the primary aim of soil survey was to achieve land capability classification on the above lines. This system designed in the United States was primarily to suit North American conditions and concerned mainly with erosion hazard

This produces unsatisfactory results as these are not fit for soil survey interpretation in many developing countries This prompted many works and organisations to evolve land capability or suitability classification that suited to the conditions and planning purposes in developing countries. One such example of such an attempt is the system that has been developed in India by **All India Soil and Landuse Survey Organisation** in 1960. It was subsequently revised and inadequacies removed in the soil survey Manual published in 1970.

The **All India Soil and Landuse Survey Organisation** (1970) has identified eight different land use capability classes with a broad classification into Land suitable for cultivation and land not suitable for cultivation.

Land suitable for cultivation

Class I: Very good cultivable land with no special difficulty in farming.

ClassII: Good cultivable. land which needs protection from erosion or floods, drainage improvement, and conservation of irrigation water

Class III: Moderately good cultivable land where special attention has to be paid to erosion control, conservation of irrigation water, intensive drainage and protection from floods.

Class IV: Fairly good land suited for occasional or limited cultivation needs intensive drainage, and very intensive treatment to overcome soil limitations.

Land not suitable for cultivation

Class V: Very well suited for grazing but not for arable farming, needs protection from gullying.

Class VI: Well suited for grazing or forestry but not for arable farming.

Class VII: Fairly well suited for grazing or forestry, but not for arable farming.

Class VIII: Suited only for wild life, recreational facilities and protection of water supplies

Evidently, the suitability classification given above is valuable for the assessment of land productivity. It is classification in terms of the limitations of soils for agricultural land use.

The classification given above is obviously quite valuable for the assessment of land productivity. It is a classification of terms of the limitation of soil for agricultural land use. It is also an interpretive grouping according to capability. Its utility for development plans can be enhanced provided the physical factors are taken into account in the course of surveying land capability. The physical factors which should be taken into account are related to: the site of the land and the soil of the land.

The site of the land	*The soil of the land*
Surface data	**Physical Properties**
Degree of slope	Depth
Slope aspect:shady or sunny	Texture
Erosional hazard	Structure
Drainage	Stoniness
Height above datum-plan	Drainage
Climatic data	**Chemical Properties, etc.**

Rainfall	Alkalinity
Temperature	Salinity and acidity
Frost free period	Water logging and flooding
Duration of snowfall	
Duration of sunshine and sunlight	

In any detailed soil survey for land capability classfication it can be safely assumed that the physical characteristic of soil are of greater value than chemical characteristic in assessing soil productivity and potentialities. This is because the chemical status of soil is artificial as it varies with the farm management and fertilising practices.If the nutrient status of the soil is poor it can be improved upon provided the physical properties of soil such as texture, depth, slope and drainage are satisfactory. Therefore, the physical properties of soil must be assessed and for such inventory of the soils detailed reconnaisence soil surveys are to be carried out.

Important Words

Capability sub class	**Capability class**	**Capability unit**
Intensity of Land Use	**Land Limitations**	**Soil Hazards**
All India Soil and Land Use Survey Organisation		**Arable Farming**

10

NATURAL REGIONS

Introduction

A region is a homogenous area in relation to a selected criteria. The division of the earth into well-marked regions has been long regarded as 'inherently geographic' or rather the fixed concept of all geographic work. A region is unique in so far as there cannot be any region of that type anywhere. Thus the regions have broad uniformity in the physical characteristics such as physiography, geology, drainage, climate, natural vegetation, animal life and soils. A region having broad uniformity regarding above factors is a natural region. At the macrolevel the homogenous character is very much present, but at microlevel these regions have striking differences in the elements of the natural environment but even then there is broad unity in their appearance which sets them apart from the other regional units adjacent to them. For example, the entire north Indian plain constitute a single region based on relief features, geomorphological characters and soil But at the lower level there are striking differences with regard to all these elements. For example, the Brahmaputra valley and the Punjab plains are both alluvial but they markedly differ in details. By and large, the local diversities and details are ignored in order to identify a broad unity component at the higher level.

Natural region demarcation of India

The division of India into natural regions is by no means an easy task. A suitable criterion has to be chosen to divide India into natural regions. These criteria can be either geological history, physiography, climate or soil. The lesser the number of variables chosen, the simpler it is to define a region, but with a lesser degree of

accuracy. The larger the number of criteria that are amalgamated, the more representative is the region However, the geology, geomorphology, climate and soil are not always distributed in such a way as to perfectly correspond with one another. They often overlap. The regional boundaries are, therefore, only approximate, not clear cut and not sharply defined. They describe only a transitional zone between the two clearly marked regional units.

Several attempts have been made to delineate the natural regions of India. The first attempt to classify natural regions in India was made by **L. Dudley Stamp**, who in 1920, prescribed a scheme of three major natural regions and 22 subregions of India. Stamp's scheme was based on the homogeneity of physiography, structure and climate. The three primary natural regions were

(1) the mountain wall,

(2) the northern plains, and

(3) the Indian plateau

The subdivisions of these major regions were based on climatic variations and physiographic variations. Stamp's work is quite valuable even in present time. The macrolevel region of the country, in fact, suggest themselves from any point of view that they are most convenient major units well established and easily comprehensible and perceptible from the view point of physical or even cultural factors or an amalgamation of two sets of factor.

Another attempt was that of **J. N. L. Becker** who in 1928 presented a scheme of natural regions which showed a very close agreement to Stamp's scheme.

It was towards the end of 1930's that some other workers, felt the need for more rigorous regionalisation of India. **Pithawala** published a work on regional division in the Journal of Madras Geographic Association in 1939. Pithawala adopted factor of physiographic uniformity as a master principle running throughout the hierarchy of regional divisions. But one master principle, howsoever, logically controlled and vigorously maintained simply cannot work as a device for the regionalisation of a large country like India. Moreover, Pithawala's boundaries in the plains, for example, between the Indus and the Ganga plains seem to be very confusing. Pithawala neglected the obvious fact that the plains because they are featureless and monotonous do not need any regional division not even on the basis of physiography. **Spate** has observed

that Pithawala's text and accompanying map are not always consistent and beset with discrepancies.

Kazi S. Ahmad put forth a macrolevel division of India separating the coastal plain from Indian plateau. However, the scheme lacks a suitable hierarchical-order His clubbing of the Himalayas with sub mountain Chho area of the Punjab on equal footing does not bear any logic to the scale of divisional scheme.

O. H. K. Spate's division of India is more detailed and refined than other works produced so far. He is in general agreement with schemes of Stamp and Becker but highly critical of Ahmad and Pithawala. Structure is the most important factor in his schemes but the division cannot be exclusively based on any one touchstone He has divided the subcontinent into three macrolevel regions based primarily on structures He has brought forth 35 regions of the first order, 9 under the three macro regions excluding islands, 74 of the second order and about 225 subdivisions. His view regarding regionalisation is very flexible and dynamic and his hierarchy is mindful of the scale and its possible variation 'since a ridge which might rank as a sub region in Peninsula would be hardly more than a feature in the Himalayas'

However, country like India, no single master principle can be adopted and the criterion has to be multifactoral and even divergent and at the same level hierarchical. This is because all the distribution factor could not be of same importance. At the same time, the distinctiveness of the region (the underlying homogeneity) will be determined only by certain of the factors or particular group of associated factors while some other sets or factors will be determined for neighbouring region This complexity arises not only because of the vast size and the resultant variations in topography, climate, soil, etc., but because of different set of man-nature interaction in different regions.

Thus the adoption of physical factors has its own limitation.

A composite scheme of regionalisation was done by **R. L. Singh** who has also incorporated, apart from natural factors, man-nature interaction. He also provides for a hierarchy of different regions within the three fold physiographic divisions of India.

Natural regionalisation of India

A modified natural regionalisation scheme of India recognises three orders of regions. Regions of the first order (1) the Himalayan mountain complex (2) the North Indian Plain (3) the Peninsular plateau (4) the Islands

(1) **The Himalayan mountain complex** - The Himalayas are macro region with a marked relief feature. These are of recent geological origin having a very rugged terrain and steep slopes, from east to west and from north to south. There is pronounced difference in climate and vegetation that accounts for the diversities within the Himalayas, which in turn, gives rise to a mosaic of second order region.

(2) **The North Indian Plain** - The North Indian Plain is characterised by very low radiator with only minor local variations Although physiographically, they do not differ much but in terms of climate and depositional activity of river, they differ from north to south, which is manifested in differences in soil and vegetation cover.

(3) **The Peninsular Plateau** - The Peninsular Plateau is the oldest segment of India. The plateau has general uniform[illegible]
Nevertheless, there are local va[illegible]
differential upliftment of the plateau surface, climate and degree of erosion and also soils and natural vegetation. Because of the vast latitudinal extent and consequently a greater climatic variation (alongwith resultant soil and vegetation variations), it has greater diversity than the northern plain.

Regions in the Himalaya

Extending in an east-west direction the Himalayas consist of a number of regional units, starting from the west are

1. Kashmir

2. Karakoram, Laddakh, Balistan

3. Himachal Himalayas and Kumaon

4. Eastern Himalayas

5. Purvanchal Hills

In the Western Himalayas, Kashmir valley is surrounded on all sides by high ountain ranges. It has its unique character. The temperate climate and the temperate nd alpine vegetation, flat alluvial plain and abundant water supply are some of the istinguishing features of this valley. But the ranges surrounding it have a variety of limatic condition and vegetation which are the result of differences in altitude, xposure to the sun and the rain bearing winds.

The complex structure of the Karakoram range and a series of old plateau surface, uch as Balistan, Aksai Chin, Deosat, etc. , replaces the Great Himalayan range on the orth. Here the climate is extremely cold with scanty vegetation.

Himachal Himalayas begin from the east of the Sutlej gorge. Further eastwards they merge into the Kumaon and the Uttarakhand regions of Uttar Pradesh. Their general height is not much and have a different rainfall pattern and vegetation as compared to the Kashmir Himalayas.

Gradually, as one proceeds from the western part to the eastern part, the Eastern Himalayas are marked as a completely separate unit. To the east of the 88°E longitude, the strong influence of the monsoon currents from the Bay of Bengal is felt. The region receives a higher amount of rainfall which results in the luxuriant growth of the tropical wet evergreen forests. Similar rainfall and vegetational growth continues further east into the Assam Himalayas without any noticeable change.

The Assam Himalayas extends southward into the Indo-Burmese Hills. They have a low relief and are far less imposing. Here the region receives low rainfall of 200 cm The forest cover is very dense and the tropical evergreen forests becomes monsoon deciduous type.

Regions in the Plains

The plain lies between the Himalayas in the north and the peninsular plateau in the south. This runs parallel to the axis of the Himalayas in the form of narrow alluvial belt. This region may be divided into :

(6) Punjab Plain

(7) Indo-Gangetic Divide

(8) Ganga plain

(9) Ganga Delta

(10) Assam Valley

The Punjab Plain lies in the extreme west and is a part of the Indus plain. It has a dry climate, showing a clean transition from the tropical monsoon to the temperate type of climate. The doabs of the Punjab plain have a distinct physical features resulting from the fluctuating river courses. The region has a dry thorny forest as vegetation.

Between the Indus and the Ganga plains, the Indo-Gangetic divide presents a unique characteristics It lies in Haryana between the Yamuna and the Sutlej and are formed by the alluvial deposits. On its outer side lies the Aravalli Hills. The Indo-Gangetic divide shows a climatic transition from the sub-humid Ganga valley to the semi-arid Punjab plain.

The Ganga plain was formed by the alluvial deposits brought down by the Ganga and its numerous tributaries. Generally the whole plain has a low, uniform relief. The climate, however, is not uniform in the region. The rainfall decreases from east to west and this has resulted in a similar change in vegetation and soil conditions from east to west Thus, the region may be subdivided into two parts - the western part is known as the Upper Ganga Plain and the eastern part is known as the Lower Ganga Plain. The Ganga river and its tributaries form an enormous delta and the alluvial deposits around it from the alluvial plain. The region has a distinct climate with high temperature and high humidity.

Towards the extreme east, the plain extends as a sub-unit marked out by the Brahmaputra of Assam valley. The valley of Assam is enclosed by the foothills of the Himalayas, the Purvanchal Hills and the outlying blocks of the Shillong Plateau. Here the region experiences a bit different type of monsoon climate with high rainfall and humidity but a shorter summer than the west. There is a very dense growth of vegetation in the region.

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Regions in the plateau

The plateau region consists of the following sub-regions :

11) Thar Desert

12) Aravalli Hills

13) Central Vindhyan uplands

14) Khandesh and Satpura - Maikal Ranges

15) Chhotanagpur plateau

16) Meghalaya Plateau

17) Kachchh and Kathiawar Peninsula

18) Gujarat plains

19) Konkan Coast

20) Goa and Kanara Coast

21) Kerala Coastal Plain

22) Western Ghats

23) Deccan Lava Plateau

24) Karnataka Plateau

25) Wainganga and Mahanadi Basins

26) Telangana

27) Southern Hills complex

28) Eastern Ghats

29) Orissa Delta

30) Andhra Coastal plain and Deltas

31) Tamil Nadu

Lying to the south of the Indo-Gangetic plain, the plateau region represents a series of plateau surfaces. The northern flank of the plateau is separated by troughs of rivers and Precambrian rocks. The plateau begins from the western side of the Aravalli, where lies the Vindhyan upland It is an arid and sandy region known as Thar Desert. The climate is extremely hot and dry and the resultant soil and vegetation are very scanty.

The Aravalli hills separate the desert from the Vindhyan upland and the Bundelkhand gneissic region lying to the east. This is a hilly region and the hills are quite pronounced in Udaipur whose western slopes are well forested because they receive quite an amount of rain The region situated to the north of Ajmer, however, are devoid of any vegetation

Towards east, lies the Central Vindhyan upland consisting of the Malwa plateau and the Bundelkhand. The *region is mainly composed of gneiss* and marked with highly dissected hill ranges of Vindhyan, Bhanver and the Kaimur Hills. Except for the narrow river basins, the whole region generally has shallow soil. The vegetation is not very dense and varies from tropical dry deciduous to the tropical thorny types.

The plateau region consists of scarped plateau, which are also steep sided and are called the Satpura, Mahadeo, Maikal ranges. The Tapti river has formed a trough here in which moderate thickness of alluvium is deposited by its tributary, the Purna.

The alluvium basin, known as Khandesh, lies between the Ajanta Hills and the Satpura Range.

On the eastern side of the Satpura Range lies the Chhotanagpur plateau. It has varying altitude. The high rainfall and humidity in the region has resulted in luxuriant growth of tropical moist deciduous forest.

On the outline of the Peninsular Plateau in the east lies the Shillong Plateau which is more dissected and humid than the Chhotanagpur plateau and is covered with Tropical Wet Evergreen forests

The Peninsula, on its western side, consists of lava formations particularly in Kathiawar and Kachchh. The Kathiawar is filled up with mud and salt wastes of Kachchh. It rises only up to 200 metres, though some hill ranges like the Gir Ranges rises a little higher. The whole region is formed by various rocks and this has resulted in variations in soil. The dry climate of the region can support only a scanty vegetation. Thus dry deciduous type of vegetation is found here.

On the eastern side of the Kathiawar and Kachchh, lies the Gujarat plains which have a regional character of their own. The region is an alluvial basin formed by the deposits brought about by the rivers like the Sabarmati, Mahi, Narmada and Tapti. This region shows a climatic transition between the humid west coast and arid and the semi-arid Rajasthan.

The western coast consists of Konkan, Goa, Kanara and Kerala coasts. The Konkan coast is influenced by marine erosion. It is a narrow piece of land dominated by scarps of the Western Ghats. The Goa and Kanara Coast lies between the Konkan coast and the Kerala coast. Its climate is very hot and humid. The rainy season gradually becomes longer towards south. The Kerala coast forming the southern end of India is distinguished with a variety of rainfall pattern and this has resulted in a variety of vegetation in the region. However, the rainfall shows a decreasing trend towards Kanya Kumari.

The Western Ghats is quite a prominent feature on the western side of the Deccan Plateau. They have an average height between 900 - 1100 m. They have a very rugged topography because of the volcanic rocks. But at a point near Goa they change physically into smoothly rounded hills of granites and gneisses. Except for certain gaps as Palghat and Shengotta the Western Ghats form a continuous barrier on the western side of India. The natural vegetation varies from Evergreen forests to Deciduous forests.

The Deccan plateau were formed by horizontal beds of lava deposits in the last phases of volcanic activity in the Peninsular India. They are in the form of flat table lands bordered by boldly rising hill ranges such as Ajanta Hills. As the plateau lies on the lee side of the Western Ghats the south west monsoon current of the Arabian Sea Branch fails to reach the region making it a semi arid region. The soil in this region

has been derived from the weathering of the lava rocks and have black colouration, hence they are known as Black Soils.

South of the Deccan Plateau lies the Karnataka Plateau formed of gneisses and granites. The region is of uniform height ranging between 450-800 m. The climate, vegetation, and soil in the region have some local variation. Due to these variations the region may be clearly divided into two sub-divisions - Malnad and Maidan.

The Deccan Lava plateau continues in a series of undulating plains and basins in the east and the north east. The
Chhattisgarh are the two prominent ba
in rainfall distribution and forest cover. Wainganga receives a rainfall lower than 135 cm while the Mahanadi basin receives a higher rainfall. The Wainganga valley is covered by sal forest while that of Mahanadi basin has rich teak forests.

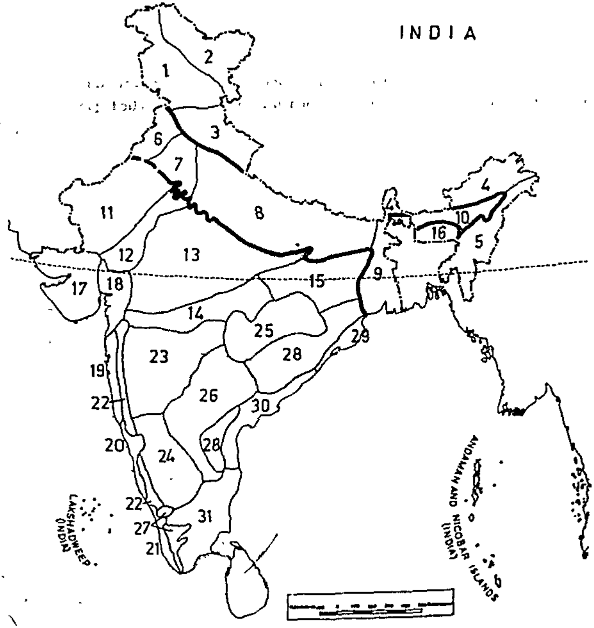
The Telangana region lies to the south-east of the Deccan Plateau. It has undergone weathering and erosion since long time and is now left as highly denuded and dissected region having isolated rock features (Monadnocks) at some places. The scanty vegetation grows only on the northern part while the southern part is covered by an expanse of tropical grasses of the Savanna type.

The extreme southern part consists of the Nilgiris, Anaimalais and the Palani, Cardamom hills which are a continuation of the Western Ghats after a wide Palghat gap These hills have a horst type of topography. The whole region is covered with rich forest of teak and sandalwood.

On the eastern part of the Peninsular plateau lies the Eastern Ghats, a contrast to the Western Ghats. The hilly Eastern Ghats consist of three main groups - the northern hills which lie between Jamshedpur and the Godavari, the Cudappah ranges lying between the Godavari and the Palkonda range and Tamil Nadu Hills between Palar and Kaveri. All these regions have local variations in rainfall and natural vegetation. The northern hills have more dense forest than the southern hills. The Tamil Nadu Hills have very small amount of forest growth on the eastern slopes.

In the extreme east, lies the East coast of India, which may again be divided into Orissa Coast, Andhra Coast and Coromandal Coast of Tamil Nadu. These Eastern Coastal plains are mainly the result of deltaic formation by rivers like the Mahanadi, Brahmani, Godavari, Kaveri, etc. The natural vegetation varies from one part to the other. In Orissa

Fig.10.1. Natural Regions of India



coast the moist condition has given rise to quite a dense forest in some parts. The Andhra coast forms a transition zone between the south-west and the north-east monsoon regimes and this is reflected in the vegetation. The Coromandal coast has its own rainfall pattern influenced by the north-east monsoon. The entire Eastern Coastal Plains have rich alluvial soil and a region of rich intensive agriculture.

Important Words

Regions
Physiographic Regions
Geographical Regions
Drainage Regionalisation
Regionalisation
Climatic Regions

APPENDIX-I

Era		Period		Age (M.y)	Epoch	Major Geological and Paleontological Events
Phanerozoic	Cenozoic	Quaternary		0 01	Holocene	Himalayan Mountain building; Age of Mammals
				2	Pleistocene	
		Tertiary		5	Pliocene	
				26	Miocene	Alpine Mountain building
				37	Oligocene	
				53	Eocene	
				65	Paleocene	
	Mesozoic	Cretaceous		136		First stages of Rocky Mountains; Age of Dinosaurs
		Jurassic		190		
		Triassic		225		Breakup of Pangaea–opening of Atlantic
	Paleozoic	Permian		280		Final assembly of Pangaea
		Carboniferous	Pennsylvanian	320		Extensive coal formation; Consolidation of continents to form super-continent of Pangaea
			Mississippian	345		
		Devonian		395		First land plants
		Silurian		430		Primitive fish
		Ordovician		500		
		Cambrian		570		First abundant shelled invertebrates
Precambrian		Proterozoic		2300		Abundant iron formations
				2800		Major gold deposits
		Archean		4600		Earliest known life (~3500); Oldest rock (~3800)
				4700		Formation of the Earth

APPENDIX - II

Local names

Duns	flat floored structural valleys
Himadri	also the name of Greater Himalaya
Babirigiri	same as above
Krishnagiri	ancient name of Karakoram
Karewas	deposits of glacial clay and other materials
Malnad	hilly area bordering the Sahyadri
Maidan	are of rolling plains with low granitic hills
Pats	flat lateritic capped summits of Ranchi
Sahyadris	another name of Western Ghats
Bhabar	pebble studded zone along the foot of the Siwalik
Terai	belt of emerging streams lost in Bhabar
Bhangar	older alluvium which forms higher ground in the interfluve area
Kankar	calcareous concretions on the Bhangar
Dhoros	remnants of former river course on recently deposited alluvium
Dhands	alkaline lakes along dry courses of river in Sindh plains
Pattis	longitudinal depression between the sand hills

Khadar	younger alluvium of the floodplains
Chhos	gully formation in the adjoining hill regions
Dhaya	bluffs of the khadar
Dhrian	shifting sand dunes in the Thar
Sar	salt-soked playa lakes on the Bagar
Rohi	Fertile tracts along Aravallis
Thali	tract north of Luni having immobile sand dunes
Bhits	Simple sand dunes on the bagar
Dhands	depressions occupied by alkaline lakes within seifs
Bhur	belt of undulating sandy uplands in Bijnor and Muradabad
Caurs	long line of marshes from Khagaria to Chhapra
Tal	lake depressions in South Bihar plains
Duars	river basin formed by the Tista and Jaldhaka
Rarh	lowland to the west of Bhagirathi
Bhils	dead arms or deferred junctions of the rivers
Kayals	lagoons and backwaters in Kerala
Adhwara	river group in Bihar
Char	river island in Bengal
Chapri	river bank made of silt

Cho	seasonal stream in Punjab with wide bed
Diar	sub stream of the main river (in Bihar)
Ghat	steps leading up to the river from where a ferry can be operated
[illegible]	floodplain area of a river in W.Uttar Pradesh
Nallah	Drain
Nadi	river

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